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Cost-Effective Live-Fire Test and Evaluation Strategies: The Missions and Means Framework

Martha K. Nelson and Dennis C. Bely

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Martha K. Nelson
Franklin & Marshall College, Lancaster, PA

Dennis C. Bely
Survivability/Lethality Analysis Directorate, ARL

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14. ABSTRACT

A methodology is presented for constructing cost-effective live-fire test and evaluation (LFT&E) programs within the Missions and Means Framework environment. Issues addressed include: the need for changes to the processes for conducting LFT&E considering system of systems combat doctrines and the design and execution of LFT&E programs to ensure (1) the collection of data relevant to vulnerability/lethality assessment decisions, (2) the generation of optimal combinations of component-, subsystem-, and system-level test data, considering cost, availability of hardware, and production schedule, and (3) the evaluation of live-fire test results in a format useful to decision-makers concerned with accomplishing system of systems collective tasks and achieving mission success in the joint environment.

A Missions and Means Framework-based system of systems task-focused LFT&E strategy is proposed to replace the traditional platform-centric strategy. The proposed strategy focuses on the extent to which the platform retains those capabilities needed for completion of system of systems tasks and the ability of the system of systems to complete current and future mission tasks in the joint environment, given the available capabilities of the platform following ballistic damage. Activity-based costing is proposed as the methodology for costing LFT&E program elements.

15. SUBJECT TERMS

live-fire test, live-fire test and evaluation, activity-based costing, missions and means framework, cost-benefit analysis, live-fire test and evaluation strategy, vulnerability risk assessment

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Contents

List of Figures

List of Tables

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Executive Summary

Historically, live-fire testing (LFT) was conceived to determine survivability and lethality of an autonomous combat platform in a combined arms team operating in a Cold War setting. In this context, LFT has been invaluable for identifying strengths and weaknesses in system and munition design, specifying limits of platform combat survivability, and validating analytical models.

Despite this success, the variety of threats and combat landscapes facing today's warfighter and the increased sophistication of platforms operating within a system of systems (SoS) context in an integrated and information-centric battlefield suggests the need for a new look at how live-fire test and evaluation (LFT&E) programs are conducted. In particular:

- How should LFT&E planning and execution change in light of SoS tactical doctrines?
- How should LFT&E be designed and conducted to (1) collect data relevant to vulnerability/lethality (V/L) assessment decisions, (2) generate optimal combinations of component-, subsystem-, and system-level test data, considering cost, availability of hardware, and production schedule, and (3) evaluate LFT results so decision-makers can ascertain mission success in the joint environment?

LFT&E has focused on critical issues associated with the tested platform, typically of the form:

- What is the vulnerability of the platform against the spectrum of current and future threats as identified by the intelligence community?
- What vulnerability reduction measures increase crew, passenger, and system survivability?
- How effective is battle damage assessment and repair (BDAR) in restoring the platform to functional combat capability?

In the context of the V/L taxonomy these issues have been addressed almost exclusively at Levels 2 (i.e., component status) and 4 (i.e., mission utility). Only to a limited extent have results been related to Level 3 (i.e., capability status). This information, cast in terms of probabilities of mission or catastrophic kills, allows only a generalization of the results in terms of a global ability to complete the spectrum of missions likely to be assigned to the platform.

But, while remaining mission utility has been represented in the context of a unit assigned to prosecute a generic mission intended for the tested platform, the platform has been considered autonomous. In that sense, concern has focused on whether the damaged platform can continue an assigned mission or perhaps through BDAR be used for an alternate mission. Damage has seldom been evaluated in the context of specific missions or complementing capabilities of other platforms within the mission-prosecuting unit.

Within the SoS environment, the objective of test and evaluation (T&E) is to facilitate the measurement and assessment of (1) the effectiveness, suitability, and survivability of platforms relevant to their contributions to the SoS and (2) the effectiveness of the SoS in achieving mission objectives at the Joint Forces Command (JFC) level. T&E, therefore, requires the assessment of the capabilities of SoS platforms, individually and collectively, to complete identified tasks in realistic scenarios.

The Missions and Means Framework (MMF) provides a structure for linking mission tasks to the capabilities required for task completion and supplies a disciplined procedure for the identification of the means to achieve mission tasks and the assessment of mission accomplishment. An MMF-based SoS task-focused LFT&E strategy is proposed to replace the traditional platform-centric strategy that emphasizes the functional capabilities of the autonomous platform. The MMF-based strategy focuses on the extent to which the platform retains those capabilities needed for completion of SoS tasks and the ability of the SoS to complete current and future mission tasks given the residual and available capabilities of the platform following ballistic damage.

The table illustrates three major areas in which the traditional platform-centric LFT&E strategy is expected to differ from the proposed MMF-based SoS task-focused LFT&E strategy.

The traditional platform-centric strategy focuses on the extent to which a platform retains battlefield combat utility (Level 4) or a general ability to complete missions likely to be assigned to the platform when subjected to current and expected future threats. The platform is considered autonomous, and little consideration is given in the critical issues to the complementary capabilities of other platforms that are part of the SoS or to the platform's role in the completion of tasks that are linked to specific missions in the joint environment.

In contrast, the MMF-based SoS task-focused strategy examines the capabilities of the platform within the context of the SoS (Level 3) and the extent to which damage to the platform from current and expected future threats affects the SoS's ability (Level 3) to complete specific mission tasks (Level 4). Redundancies and interdependencies among SoS platforms are considered in the identification of critical issues and prioritization of data voids.

With limited time and dollars to devote to LFT, shotline selection requires the prioritization of identified data voids — areas in which there is little understanding of the effects of ballistic interactions on platform capabilities. In the MMF-based SoS task-focused strategy, the limited LFT shots must be "spent" to address the most urgent questions of a platform's ability to support the SoS mission tasks. The technical risk associated with failing to address less critical capabilities in an LFT may be examined via modeling and simulation.

In the MMF-based SoS task-focused strategy, however, the focus is the capabilities of the platform within the context of the SoS and the ability to complete SoS mission tasks. The

Table. Comparison of traditional and MMF-based LFT&E strategies.

	Traditional Platform-Centric LFT&E Strategy	**MMF-Based SoS Task-Focused LFT&E Strategy**
Critical Issues	**What is the vulnerability of the platform to** current and future threats identified by the intelligence community? How effective is BDAR in restoring **the platform to functional capability** after an attack?	**What is the reduction in the ability of the SoS to prosecute typical missions after damage from** current and future threats identified by the intelligence community? How effective are BDAR **and other maintenance actions** in restoring **SoS capabilities critical to mission prosecution after an attack?**
Shotline Selection	Platform: Based on technical risk associated with the inability to determine **platform capability** as the result of ballistic damage.	Platform: Based on technical risk associated with the inability to determine the **effect on mission prosecution caused by loss of platform capabilities** as the result of ballistic damage.
Damage Assessment	Platform: • Map **to remaining combat utility via Damage Assessment List (DAL) or other $O_{3,4}$ construct.** Crew: • Map crew incapacitation to **remaining combat utility via DAL or other $O_{3,4}$ construct.**	Platform: • Map **to remaining SoS capabilities by analysis and operational-type tests.** Crew: • Map crew incapacitation to **platform loss of capabilities and confirm remaining SoS capabilities by analysis and operational-type tests.**
	BDAR: Determine expedient repairs that can be made to restore **platform to some level of combat utility.**	**Mission Damage Assessment and Repair:** • BDAR: Determine expedient repairs that can be made to restore **some platform capabilities during and immediately following an engagement.** • **Other maintenance procedures: Conduct further repair to anticipate future engagements during the mission.**

remaining capabilities following an LFT can be determined in laboratory settings and through quasi-operational tests using companion vehicles to confirm the usefulness of residual capabilities within the SoS construct or to develop and validate “workarounds” to complete mission tasks with capabilities remaining within the SoS (i.e., damaged platform plus companion platforms).

Thus, the emphasis of the proposed MMF-based strategy on SoS tasks is reflected in both the planning for LFT and the evaluation of LFT results. In LFT planning, critical issues that emphasize recoverability are identified with the perspective directed toward SoS operations in the joint environment. Modifications to shotline selection and damage assessment are expected, as the focus expands to include the long-term, as well as the short-term, needs for SoS

capabilities. The strategy allows for a realistic assessment of the technical risk associated with foregoing test shots that may be of interest at the platform level but are not critical to understanding SoS effectiveness. In evaluation, the roll-up of platform LFT program results to the SoS level provides decision-makers with a better grasp of the ability of the unit of operation to complete tasks to standards under given conditions and the risks associated with alternative courses of action.

With consideration to the risks associated with vulnerability assessment, a structured process for building cost-effective LFT&E programs in an MMF environment is presented. This methodology includes the identification and prioritization of data voids and the selection of the optimal program elements for addressing those voids, considering time, production schedule, hardware availability, and cost. Activity-based costing (ABC), proposed as the appropriate methodology for costing LFT&E program elements, allows the value added in completing LFT&E program elements, activities, and sub-activities to be weighed against the costs incurred. The identification, measurement, and reporting of costs according to established standards, consistent across time periods and comparable across systems, and the establishment of a database accessible for purposes of estimating costs pre-test and evaluating cost variances post-test are recommended.

Designing a cost-effective LFT&E program requires meeting LFT&E objectives with consideration given to the limited resources available. ABC provides the framework for the decision-maker to view LFT&E program elements from both strategic and operational perspectives, eliminating non-value-added elements and activities and seeking ways to make value-added elements and activities more efficient and effective.

1. Introduction

1.1 Background

Live-fire testing (LFT) is now in its third decade. Motivated by Joint Live-Fire (JLF) testing of front-line U.S. platforms and munitions beginning in 1984, Live-Fire Test and Evaluation (LFT&E) became a formal part of the Department of Defense (DoD) acquisition process in 1987.

U.S. Code (Title 10 U.S. Code Section 2366) mandates LFT&E for covered systems, major munitions programs, missile programs, and product improvements to covered systems before they can proceed beyond low-rate initial production (LRIP).[*] The objective of an LFT&E program is to support a "timely and thorough assessment of the vulnerability/lethality of a system as it progresses through its development and subsequent production phases." An effective LFT&E program demonstrates "the ability of the weapon system or munition to provide battle resilient survivability[†] or lethality and provide[s] insights into [both] the principal damage mechanisms and failure modes occurring as a result of the munition/target interaction and …[the] techniques for reducing personnel casualties or enhancing system survivability/lethality (DA Pam 73-1, p. 198)."

A vulnerability or lethality assessment strategy[‡] established early in the development of a weapon system has the potential to detect system vulnerabilities or deficits in system's lethality, as well as to reduce or minimize the costs associated with combat losses and retrofits of systems in the late stages of production. An LFT&E program is designed with the purpose of collecting data relative to certain vulnerability/lethality (V/L) characteristics of the platform or munition. A typical program includes various combinations of coupon-, component-, subsystem-, and system-level tests and is supported by data from modeling and simulation (M&S); design analyses; analyses of combat, safety, and mishaps; controlled damage experiments (CDE); and developmental and operational tests.[§] In this report, it is assumed that the focus of LFT&E programs is ballistic threat effects.[**]

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[*] A covered system is an Acquisition Category I or II program vehicle, weapon platform, or conventional weapon system that includes features designed to provide some degree of protection to users in combat. A commercial or nondevelopmental item may be a covered system or a part of a covered system, depending upon its intended use.

[†] Survivability is "the capability of a system and crew to avoid or withstand a manmade hostile environment without suffering an abortive impairment of its ability to accomplish the designated mission." Survivability consists of susceptibility, vulnerability, and recoverability. The focus of the LFT program is vulnerability (i.e., kill given a hit) (DA Pam 73-1, p. 296 [2003]).

[‡] In this report, vulnerability (lethality) assessment strategy is defined as the overall plan designed with the purpose of collecting sufficient relevant data for evaluators to assess a system's vulnerability (lethality). As the term in used in this report, the strategy includes activities conducted by government and nongovernment analysts and testers, as well as government evaluators.

[§] A developmental test is a "generic term encompassing M&S and engineering type tests that are used to verify that design risks are minimized, that safety of the system is certified, that achievement of system technical performance is substantiated, and that readiness for operational T&E is certified." LFT&E may be classified as a developmental test (Army Regulation 73-1, p. 17 [2004]).

An operational test is a "field test of a system…under realistic operational conditions with users who represent those expected to operate and maintain the system when it is fielded or deployed" (Army Regulation 73-1, p. 21 [2004]).

[**] It is recognized that V/L assessment strategies must consider the effects from ballistic and nonballistic threats. Some LFT&E programs are extended to include certain conventional nonballistic threats, such as lasers and high-powered microwaves.

As part of the V/L assessment strategy for a system included under the U.S. congressional LFT&E mandate, a *Full-Up System-Level (FUSL) LFT&E* must be completed by independent agencies prior to the system entering full-scale production.* A FUSL LFT includes "realistic survivability testing …testing for vulnerability of the system in combat by firing munitions likely to be encountered in combat…at the system configured for combat" or "realistic lethality testing…testing for lethality by firing the munition or missile concerned at appropriate targets configured for combat (Title 10 U.S. Code Section 2366)."

Because significant resources may be consumed in its planning, execution, and evaluation, it is important to understand the role of FUSL LFT in a V/L assessment strategy and weigh the costs and benefits of competing alternative assessment plans.† The Secretary of Defense may waive the application of tests, if the Secretary certifies to Congress that a FUSL LFT of such a system or program would be unreasonably expensive and impractical. A waiver and alternative LFT&E strategy must be submitted and approved by Milestone B (i.e., approval to enter System Development & Demonstration Phase) (see figure 1).

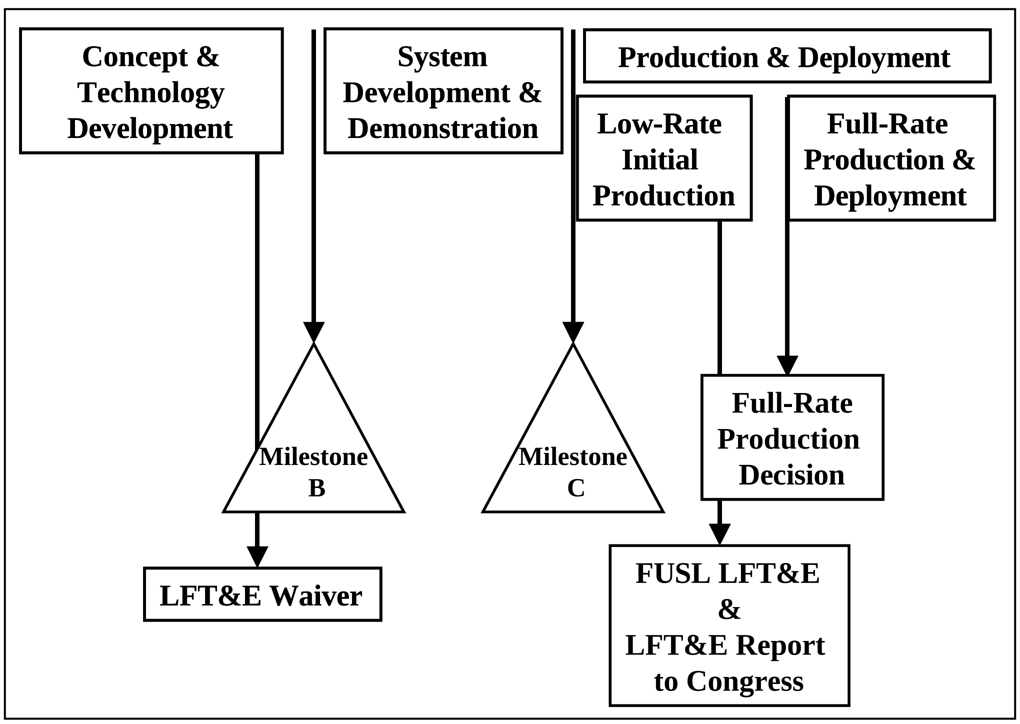

Figure 1. Defense acquisition time line.

*A LFT is defined as a test within the LFT&E program approved by the Office of the Secretary of Defense and includes firing of actual munitions at target components, subsystems, or system-level targets to examine personnel casualty, vulnerability, or lethality issues. A FUSL LFT is defined as the "testing that fully satisfies the statutory requirement for realistic" (in threat, configuration of target, and operating environment) "survivability testing or realistic lethality testing (as defined in Title 10 of the USC) (DA Pam 73-1, p. 203)."

†In LFT legislation, an *alternative strategy* is a strategy that does not include FUSL LFT. In this report, however, the term alternative, as in *alternative strategy* or *alternative plan*, is defined more broadly and is used to indicate more than one option or a choice among options. Therefore, one or more alternative V/L assessment strategies or plans may include FUSL LFT as an element.

1.2 Contributions of LFT&E Programs

Since 1985, more than 35 U.S. Army platforms and munitions have undergone FUSL testing under the JLF or Congressional-mandated LFT programs.* The focus over this period has been on the V/L aspects of platform or munition performance in a combined arms team in a Cold War setting. During this period, improvements in test planning and execution have led to an increase in the credibility of test results. Criticisms leveled against the Services during Bradley LFT in 1985-86 motivated examinations of how system-level vulnerability and lethality tests were planned and conducted. Plagued by a plethora of threat munitions (in vulnerability tests), platform design weaknesses potentially contributing to crew casualties and system vulnerability, and combat conditions to be replicated, test planners developed systematic processes for shotline selection, shot ordering, and damage assessment that were derived from pre-test identification of critical issues for the LFT.

Identification of the critical issues is the key to LFT success. Only with a set of critical issues can the tester hope to extract test data that are relevant, useful, and necessary. Test execution requires discipline to collect data of the resolution and quantity needed to address the critical issues. Hardware availability, cost, and schedule restrictions make it difficult to achieve all test objectives. But, through careful test planning, including forecasting spare parts requirements, and shot sequencing, test processes and procedures have evolved that are consistent with, and supportive of, the critical test issues. Addressing critical issues in the planning, execution, and analysis of live-fire tests in an open environment with adequate oversight by all levels of Service and DoD chains of command has improved the credibility of the test results and subsequent evaluations significantly.

LFT&E has been beneficial in many ways. Specifically:

- Strengths and weaknesses of system designs have been identified and verified. Development of critical issues facilitates identification of design features of questionable robustness and the development of a strategy to investigate these features. For example, LFT has demonstrated that certain munitions were incapable of perforating threat vehicle armor. In most such cases, the problem was rectified through changes in the penetrator design.† But not all news about system performance has been bad news. For example, it has been shown repeatedly that not all impacts by overmatching munitions are lethal to either the system or crew. In fact, the probability of crew casualties or system loss of combat utility has often been shown to be much less than expected prior to testing.

  Typically, during the acquisition program, tests are conducted to verify that design requirements have been met. Historically, these tests have more often been conducted at the component or subsystem level than at the system (platform) level. Nevertheless, testing

* In a *lethality* FUSL LFT of a platform, the focus is the terminal effects of the munition on the target, given a hit. The FUSL LFT may be limited to tests of the munition and be totally independent of the identity of the firing platform.

† No specific systems are identified in order to keep the discussion unclassified.

sought to assure compliance with design requirements. These tests were never intended to define the upper limits of survivability or lethality. LFT, on the other hand, does not directly address design requirements. Rather, it seeks to examine survivability and lethality in the context of the "full spectrum of battlefield threats, to include overmatching threats (DA Pam 73-1, p. 203)." Consequently, testing is often done with the expectation of significant damage. Testing strives to determine how much damage occurs, whether the damage is expected, whether it can be reasonably mitigated, and whether it can be repaired using Battle Damage Assessment and Repair (BDAR) practices. This has produced valuable information to the designer as well as to the combat user.

- Crew hazards from the spectrum of insults have been quantified. Prior to LFT, only penetration injuries received any serious analytical consideration. Injuries from blast, thermal effects, and toxic gases were either ignored or feebly accounted for by *adjusting* component kill probabilities. LFT now gives considerable attention to crew hazards and, as a result, there is a much better understanding of the hazards all insults really pose to the crew and of the conditions under which crew injuries can be expected.

  Overall, penetration injuries remain the largest contributor of crew injuries. However, testing has shown that other insults are significant threats to crew survivability. For example, toxic gases from burning ammunition and other combustibles have been identified as significant hazards if no protection is afforded through vehicle or individual protection. With protection, the hazard is greatly mitigated. Flash blindness, once thought to be a significant hazard, seldom causes serious incapacitation. Overpressure from reactions of stowed ammunition can be a serious threat to crew survivability. Overpressure from attacking munitions generally does not affect the crew of heavy fighting vehicles, but the hazard is more severe for crews inside light vehicles.

- Weaknesses and shortcomings in analytical models have been identified. Prior to the LFT era, even so-called high-resolution component-level models did not have the resolution needed to investigate specific physics-of-interaction phenomena and quantify the effects of these phenomena at the component level. Those models were, in the main, expected value models that predicted a point estimate of the probability of the outcome of a given threat-target interaction. This expected value was often interpreted as the most likely outcome. The models neither predicted the specific outcome of a particular test nor gave evidence of the range of outcomes that might be expected.

  LFT motivated a long-term investigation of not only the quality of the models being used, but also of the type of model predictions that are needed. As a result, models now predict distributions of possible outcomes rather than a single expected value, are of much higher resolution through more faithful target representation, and account for additional damage mechanisms and crew insults. Much more work is needed to perfect these models and, indeed, much is ongoing. Computation architectures are being developed to improve

efficiency and accommodate improved algorithms for computing component damage and system response. Significant resources are being devoted to the development of new algorithms that are based on principles of physics and chemistry with less dependence on large amounts of system-specific empirical data.

LFT has motivated true analytical model validation. Three decades ago, critics outside the LFT community believed the only true indication of V/L could be obtained through destructive testing. They believed analytical models were not sufficiently reliable to give a true picture of system vulnerability or munition lethality. At the other extreme, a few people within the V/L community advocated that testing was not only unnecessary, but it was wasteful because analytical models could account for, and quantify, all significant V/L phenomena. Now nearly everyone recognizes that not only are both testing and analysis necessary, they can and must be complementary. Analysis guides test requirements by identifying areas of uncertainty and quantifying the consequences of particular potential weaknesses of a design. Testing provides diagnostics for model performance, guides development of improved algorithms, and supplies data with which the models can be accurately validated at the algorithm and model levels.

Obviously, all threat-target impact conditions cannot be tested. Model validation derived from comparisons of model predictions with test outcomes during the last two decades has given the V/L community confidence that models can be used to extend LFT results to conditions not tested. Further, the models have been used to limit or eliminate shots for which the ability of models to predict the outcome has been demonstrated. Such proactive use of V/L models has resulted in smarter and more cost-effective testing.

1.3 Critical Issues of LFT&E Programs

Since the onset of JLF and Title 10 LFT&E, the focus has been directed toward defining critical issues associated with the tested platform or munition. Typically, critical issues in *vulnerability* LFT&E have been identified as follows:

- What is the vulnerability of the platform against the spectrum of current and future threats as identified by the intelligence community?
  - What are the major causes of crew and passenger casualties?
  - What are the vulnerabilities of the platform to perforating and nonperforating threats?
  - What is the remaining platform mission utility after the shot?
- What vulnerability reduction measures are effective in reducing crew, passenger, and system vulnerability?
- How effective is BDAR in restoring the platform to functional combat capability following an attack?

Each of these issues is generally subdivided into several sub-issues relating to specific phenomena of interest, for example, contribution of stowed ammunition to casualties, design features of the specific system being tested, and performance of specific vulnerability reduction designs such as fire suppression hardware.

In the context of the V/L taxonomy (see figure 2),* these issues have been addressed almost exclusively at Levels 2 (i.e., component status) and 4 (i.e., mission utility). Only to a limited extent have results been related to Level 3 (i.e., capability status). Damage assessment results have been presented to identify specific components and subsystems that were either damaged or proved to be unexpectedly robust. From this information, it has been possible to establish design changes that were needed or desired and the consequences of not implementing those changes. Results for armored fighting vehicles have also been presented at Level 4 with the aid of the damage assessment list (DAL).†

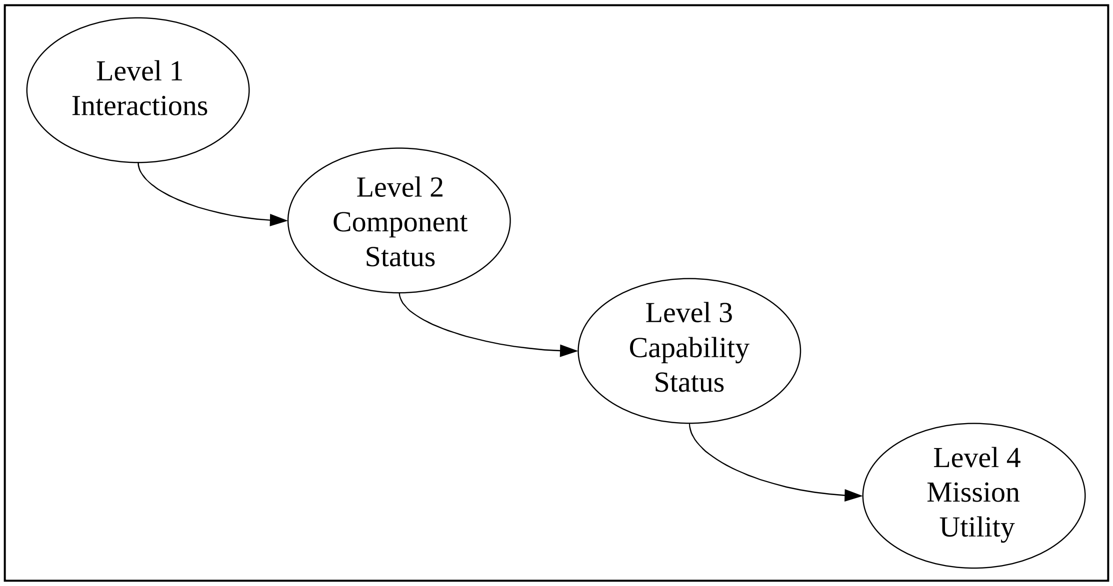

Figure 2. The V/L taxonomy.

This information, cast in terms of probabilities of mission or catastrophic kills, allows a generalization of the results and examination of the outcome in terms of a global ability to complete the spectrum of missions likely to be assigned to the platform.

But, while remaining mission utility has been represented in the context of a unit assigned to prosecute a generic mission intended for the tested platform, the platform has been considered

*The taxonomy of the V/L analysis process was first introduced in Deitz and Ozolins (1989).

†Similar constructs are used for other types of platforms, including aircraft. LFT results can be presented at Level 4 only with the use of an operations research mapping format, such as the DAL. Level 4 metrics are neither observable nor testable in a laboratory setting.

autonomous. In that sense, concern has focused on whether the damaged platform can continue an assigned mission or perhaps, through BDAR, be used for an alternate mission. Damage has seldom been evaluated in the context of specific missions or complementing capabilities of other platforms within the mission-prosecuting unit.

Historically, LFT was conceived to determine survivability and lethality of an autonomous combat platform in a combined arms team operating in a Cold War setting. That is, battle doctrine addressed large-scale confrontations between U.S. and U.S.S.R. forces engaging in mostly rural areas. While the concept of war has changed in recent years, the modus operandi of LFT, for the most part, has not changed. It still focuses on determining the vulnerability of a single platform or the lethality of a munition fired at an autonomous platform. LFT&E programs for recent systems of interest have, to be sure, recognized that platforms no longer operate as autonomous entities because platforms and even units are necessarily linked by vast amounts of real-time information that directs the conduct of even individual battles. But, so far, LFT strategies have chosen to address the linkage between individual platforms and their units through force-on-force M&S and not through the LFT planning or damage assessment processes.

As valuable as LFT&E has turned out to be, the design and conduct of LFT and the use of data produced by that testing need to be changed to better evaluate the subject platform in the System of Systems (SoS) context. Changes in the kinds of wars fought, the kinds of systems employed, the use of these systems on the integrated and information-centric battlefield, and the evolving nature of the acquisition process demand a fresh look at LFT to make it more relevant and useful in the future.

It is the premise of this report that LFT&E must not operate as an isolated activity during system acquisition. The LFT&E program must reflect the role of the tested platform in an SoS construct and address individual platform capabilities in the context of the collection of platform capabilities available to the unit commander to prosecute a wide range of missions. Further, while actual ballistic testing will generally involve a single platform, damage assessment can be expanded to experimentally evaluate remaining capabilities of the damaged platform in a unit setting through select quasi-operational tests.

Live-Fire Testing and, most importantly, Evaluation, must be considered in the context of SoS constructs where individual platforms are linked by sophisticated information networks. Critical issues should reflect platform capabilities that are required to accomplish a mission by a collection of platforms. It may turn out that a platform capability critical for mission performance in the context of autonomous operations can be provided by a companion platform when the small unit is considered. The consequence of developing critical issues from this point-of-view is that shot selection may be different than that appropriate for an autonomous platform.

Damage assessment has traditionally cataloged damage inflicted in an LFT and examined the effects of that damage in limiting capabilities of that platform. For example, damage to a sight is evaluated in terms of reducing the firepower of the vehicle. Considering LFT&E from an SoS

perspective requires the damage to be evaluated in terms of how the mission completion capability of the entire unit will be affected. One method of doing this is through quasi-operational testing where the damaged vehicle can operate with companion vehicles to determine the true effect of any subsystem functional degradation. Obviously, not all test outcomes can be assessed in this manner. Resources will allow only a small sampling of numerous possibilities, but even some such tests will shed light onto our ability to predict the extent to which missions will be jeopardized by damage to given platforms.

1.4 Report Objectives

The major objective in developing an effective Test and Evaluation (T&E) plan for a platform that is part of a complex SoS is to facilitate the measurement and assessment of (1) the effectiveness, suitability, and survivability of the platform relevant to its contributions to the SoS and (2) the effectiveness of the SoS in accomplishing the assigned operational missions in the joint operational environment. This report describes a methodology for constructing cost-effective programs for LFT&E, a major component of the T&E plan and the V/L assessment strategy, within the Missions and Means Framework (MMF) environment.

The report addresses the following issues:

- How should the processes for conducting LFT&E change in light of the tactical considerations of SoS combat doctrines?
- How should the LFT&E program be designed and conducted to ensure (1) the collection of data relevant to V/L assessment decisions, (2) the generation of the optimal combination of component-level, subsystem-level, and system-level test data, with consideration given to cost, availability of hardware, and production schedule, and (3) the evaluation of LFT results in a format that is useful to decision-makers concerned with accomplishing SoS collective tasks and achieving mission success in the joint operating environment?

2. Missions and Means Framework

The MMF provides a structure for "specifying the military mission and quantitatively evaluating the mission utility of alternative warfighting Doctrine, Organization, Training, Materiel, Leader Development, Personnel, and Facilities (DOTMLPF) services and products (Sheehan et al., 2004b)." It serves as a bridge from the warfighter operational community to the warfighter support communities (see figure 3).

The framework supplies a disciplined procedure for explicitly specifying the mission, allocating the means, and assessing the accomplishment of the mission. A brief description of the components of the MMF in the interaction of friendly (OWNFOR) and opposing (OPFOR) forces follows.

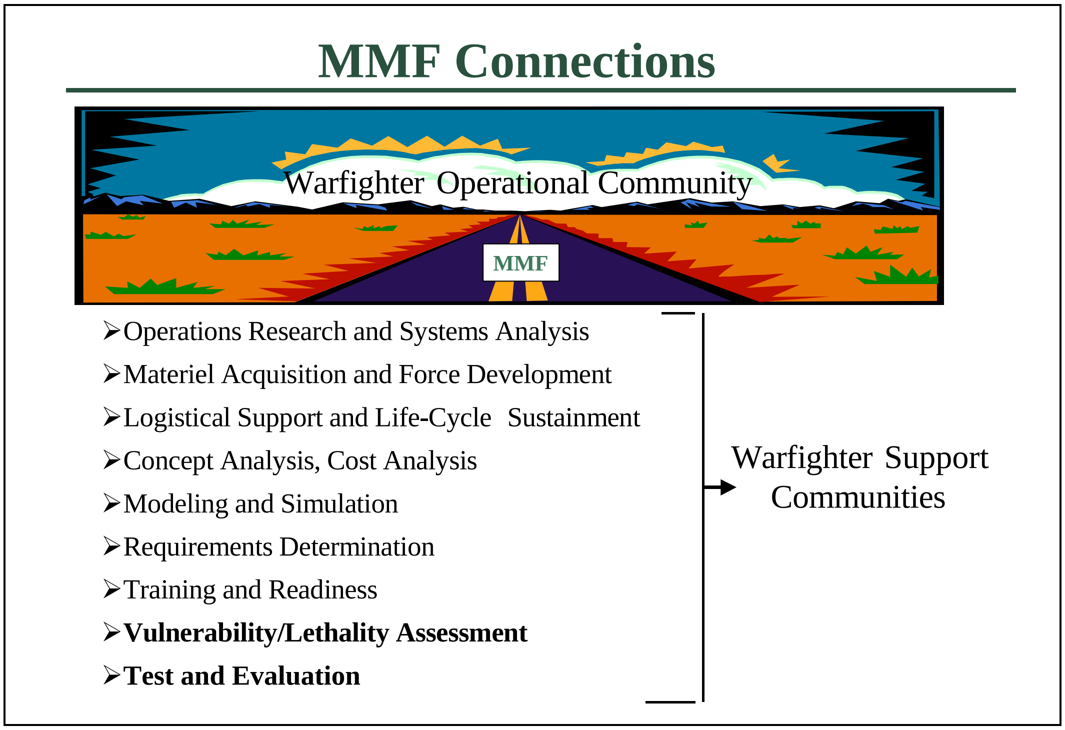

Figure 3. MMF links between warfighter operational and support communities.

Figure 4 represents the activity of a mission under conditions created by location and time of mission performance. Specified, implied, and essential tasks, enabled by capabilities, are performed by task-organized units. The MMF is composed of seven levels including:

7. the mission—the assignment that indicates the purpose of actions to be taken and the required outcomes;

6. the environment—the military, civil, and physical context and unit-specific conditions that explain the circumstances under which actions will be taken in the accomplishment of the mission;

5. the location and time—the index that describes the when and where of actions to be taken;

4. the tasks and operations —the activity components that are needed to accomplish the mission;

3. the functions and capabilities—the abilities to move, sense, communicate, engage, etc., that are required for task completion;

2. the components of forces—the networks of units, personnel, and equipment that provide the capabilities to complete the tasks; and

1. the interactions—the actions that result in changes to the components of forces through the processes of mission execution (i.e., normal wear and tear and damage from hostile forces).

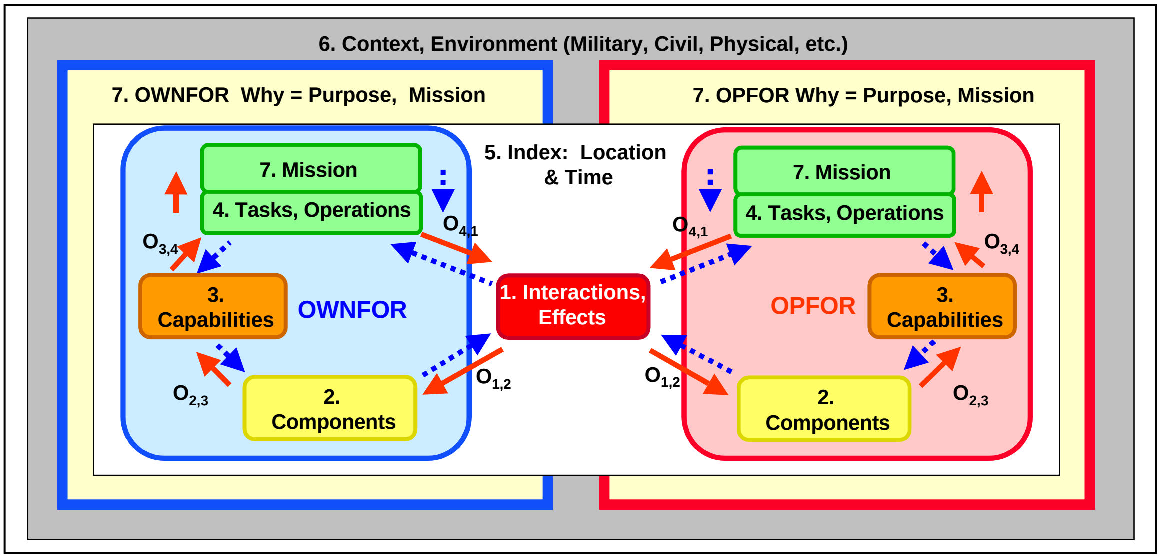

Figure 4. Two-sided MMF.*

The MMF also includes four operators, illustrated in figure 4 by the pairs of arrows that connect the four levels of (1) interactions/effects, (2) components/forces, (3) functions/capabilities, and (4) tasks/operations/mission. Beginning with OWNFOR tasks and proceeding in a counter-clockwise direction (top-down direction)† toward capabilities, the blue arrows indicate the concurrent synthesis and decision-making process; causal, time-forward execution and adjudication of outcomes is explained by proceeding in a clockwise direction (bottom-up direction)‡ from interactions and effects toward tasks and operations.

Mission-task decomposition, an important component of the mission analysis process explained in the preceding paragraphs, describes the tasks that must be completed to accomplish the mission. Tasks are derived from the Universal Joint Task List (UJTL),§ the Service Task Lists (i.e., Army Universal Task List [AUTL], Universal Navy Task List [UNTL], and Air Force Task List [AFTL]), and Mission Training Plans (MTPs) and associated Operations Plans (OPLANs) or Operations Orders (OPORDs). Task lists define both conditions (physical, military, and civil environment) and measures of performances (i.e., measure, scale, and criterion-standard) for task completion.

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*Figure adapated from Sheehan et al. (2004a). OPFOR movements would be the opposite of OWNFOR movements (i.e., OWNFOR counter-clockwise would be OPFOR clockwise and OWNFOR clockwise would be OPFOR counter-clockwise).

†Clockwise direction (bottom-up direction) for OPFOR description.

‡Counter-clockwise direction (top-down direction) for OPFOR description.

§Joint operations require the use of UJTL tasks. The UJTL lists tasks in a hierarchical manner, identifying what is to be performed by Joint forces, under Joint command, using Joint doctrine. CJCSM 3500-04C, Universal Joint Task List (2002), states that the UJTL "serves as a common language and common reference system for joint force commanders, combat support agencies, operational planners, combat developers and trainers to communicate mission requirements."

The MMF provides a layered perspective, identifying missions and tasks by the levels of war. For example, as illustrated in figure 5, the Strategic National level's mission to protect national interests might be composed of tasks to restore the legitimate government (e.g., employ forces, decide on need for military action) and require national intelligence and communications assets. A Strategic Theatre level that assumes the mission to restore the legitimate government may complete tasks to establish certain military and civil conditions (e.g., conduct operations in depth) and employ a joint task force to provide the necessary capabilities. The mission of the Operational level to help establish the desired military and civil conditions may require the completion of tasks to isolate the rebel government (e.g., conduct offensive operations) and utilize air, ground, maritime, and special operation forces elements. The Tactical-Joint level may employ a U.S. Army Future Combat System (FCS)-equipped Brigade Combat Team (BCT) to complete tasks to prevent the reinforcement of the enemy's capital (e.g., conduct an attack) in an attempt to accomplish its mission to help isolate the rebel government. The Tactical-Service level, given the mission of preventing the reinforcement of the capital by accomplishing tasks focused on blocking the access on the main route into the capital (e.g., seize a specific area) may choose to employ a combined arms battalion (CAB).[*] As this brief example illustrates, the mission and its task components, as well as the capabilities and the force assets required to provide the identified capabilities, differ with the layer or level of war considered.

The task organization process provides a basis for the identification of the force assets to best achieve the mission goals by linking (1) the capabilities to tasks, given the actual or anticipated conditions and standards, and (2) the capabilities to the resources available. The difference (i.e., delta) between the capabilities required and the capabilities supplied by available force assets is addressed with a recommended solution in one or more of the DOTMLPF areas (Bray, 2005).

3. The MMF and LFT&E in SoS Environment

Linking missions and means is vitally important to a multitude of defense/military efforts,[†] including the development of combat strategies, the preparation of an analysis of alternatives (AoA), the development of training programs, the development of M&S tools, system development and acquisition, the development of study, experimentation and test plans, the assessment of readiness, the estimation of mission costs, and the planning, conduct, and evaluation of developmental, operational, and LFT programs and their results. All of the aforementioned efforts must be considered within the complex SoS environment.

[*]The UJTL defines tasks at strategic and operational levels, and the Service-specific task lists define the tactical-Service tasks.

[†]The MMF supports the Joint Capability Integration and Development System, one of the three principal decision support processes for transforming the military forces according to the future DoD vision (Tanenbaum and Bray, 2005).

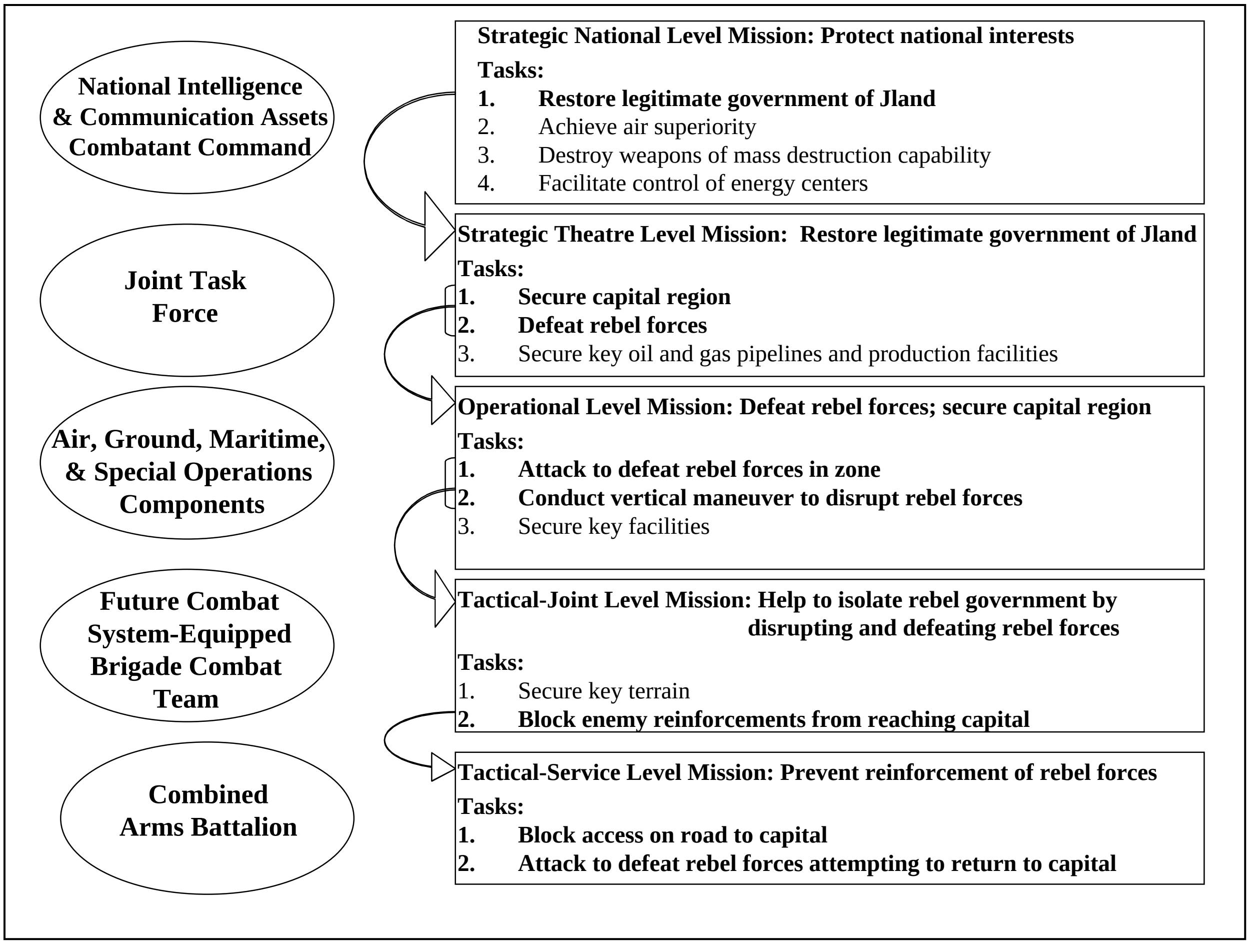

Figure 5. Strategic national to tactical nested tasks.*

Within the SoS environment, the objective of T&E is to facilitate the measurement and assessment of (1) the effectiveness, suitability, and survivability of platforms relevant to their contributions to the SoS and (2) the effectiveness of the SoS in achieving mission objectives at the Joint Forces Command (JFC) level. T&E, therefore, requires the assessment of the capabilities of SoS platforms, both individually and collectively, to complete identified tasks in tactically realistic scenarios. The assessment of task performance requires an understanding of task sub-parts, the standards of performance expected, and the conditions under which the tasks may be performed, including the impact of those conditions on task performance. The rolling up of T&E results from the platform/SoS level to the JFC level requires an understanding of the mission hierarchy that induces tasks, conditions, and standards, as well as an understanding of the hardware hierarchy(ies) that induces capabilities.

*Figure modified from Sheehan et al. (2004b).

As illustrated in figure 6, the gap between the two identified hierarchies (i.e., ***T***asks and ***C***apabilities) leads to the question, "Do we have enough capability to complete tasks to standard under the given conditions?" or "Does the mission capability package meet the mission capability requirement?" To address these questions, decision-makers must consider the acceptable levels of risk of failure in completing the mission, as well as alternative courses of SoS action (Tanenbaum and Bray, 2005). The vulnerability and lethality of platforms and their munitions in ballistic interactions,* assessed in LFT&E programs, are important factors in this decision process.

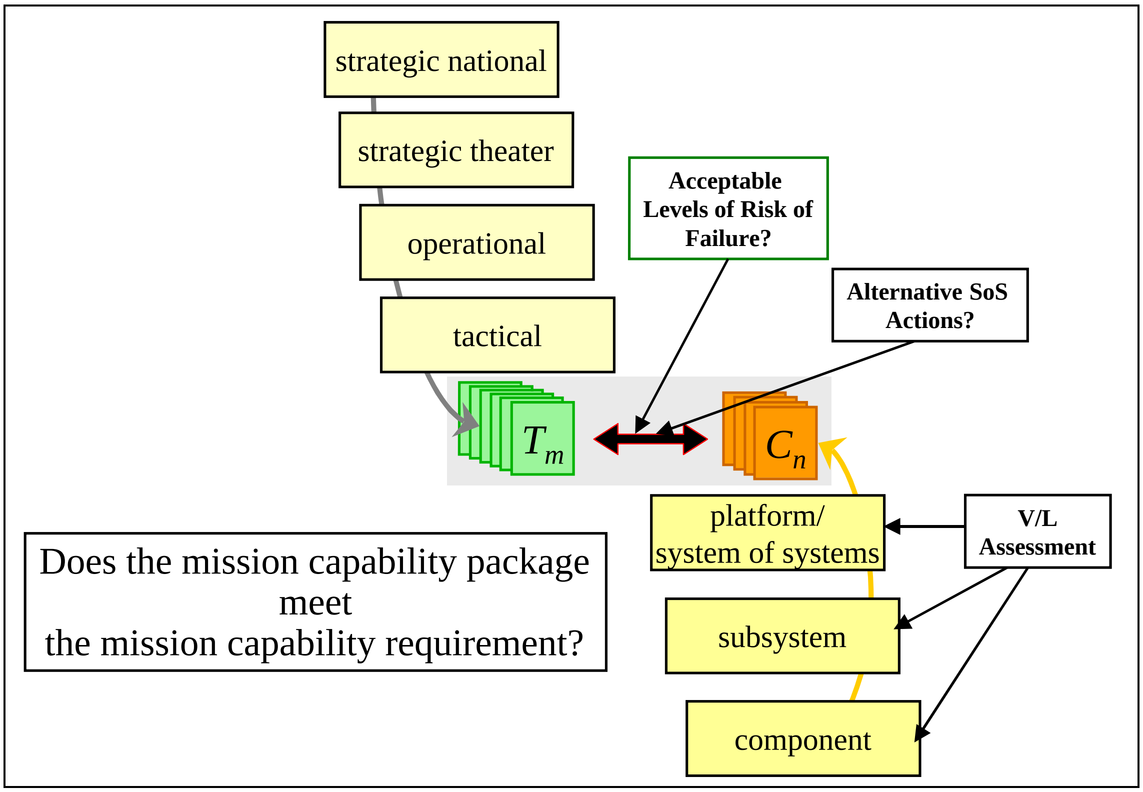

Figure 6. Assessing capabilities against mission/task requirements.†

3.1 Cost-Effective V/L Assessment in SoS Environment

In the traditional platform-centric view of *vulnerability* assessment, attention is directed toward threat-system interactions that degrade the system's capabilities or that result in injuries to the system's crewmembers and passengers. The question addressed is, "To what extent will the interactions of the weapon system and the threats that the system is likely to encounter in combat result in personnel casualties (i.e., personnel vulnerability) or the loss of the system's capabilities (i.e., system vulnerability)?"

* Although some programs consider certain conventional nonballistic threats (e.g., lasers, high-powered microwaves), it is assumed in this report that the focus of LFT&E programs is ballistic interactions.

† Figure modified from Tanenbaum and Bray (2005).

In a similar manner, *lethality* assessment has been historically viewed as a process by which decision-makers ascertain the extent to which the interactions of the system and the threat platform (i.e., opposition's platform) eliminate or degrade the operational functions of the threat platform, resulting in the reduction of the levels of the threat platform's capabilities. This includes damage to or catastrophic loss of the threat platform, as well as casualties that render threat the platform's crew unable to complete the mission tasks of the opposition.*

How does the process for conducting V/L assessment and LFT&E change in light of the tactical considerations of SoS combat doctrines? First, the significance of threats on the battlefield can be assessed in terms of their potential impact on the SoS rather than their impact on a single platform. Regional threats and widely proliferated threats may pose a greater hazard to a unit's ability to perform its mission than a less common, but more damaging threat. For example, a munition that disrupts communications among multiple platforms could impact a unit's assigned mission more severely than the catastrophic loss of a single platform to a severe overmatch. Second, in the SoS environment with the emphasis on joint operations, it is important to extend the focus of vulnerability (lethality) assessment beyond the evaluation of the functional capabilities of the platform (threat platform) and include the assessment of the capabilities of the SoS and subsequent prosecution of the mission at the JFC level.

It is proposed that in an effective vulnerability LFT&E program in an SoS environment, evaluators must assess (1) the extent to which the weapon system retains those capabilities determined (at time of acquisition) to be needed for completion of SoS tasks, when the system interacts with the full spectrum of ballistic threats it is likely to encounter in combat, and (2) the extent to which the SoS is able to complete the identified mission tasks in the joint environment, given the residual and available (i.e., as determined in LFT&E) capabilities of the tested platform. Likewise, an effective lethality LFT&E program evaluates (1) the extent to which a threat platform retains the capabilities needed for completion of its mission tasks following ballistic interaction with the assessed munitions and (2) the extent to which the SoS is able to complete the identified mission tasks in the joint environment, given the results of the lethality tests (see figure 7).

To make V/L assessment and LFT&E not only effective, but also cost-effective, budgetary constraints must be considered. To address the question posed in figure 7, V/L assessment strategies and LFT&E programs must be efficient and designed with an eye toward the final objective: the assessment of the ability of the platform to prosecute the mission as a component of an SoS in the joint environment.

*The word "lethality" is often used in a more narrow sense with the focus solely on damage to the target platform, and the term "effectiveness" is used to capture the damage and consequences of that damage.

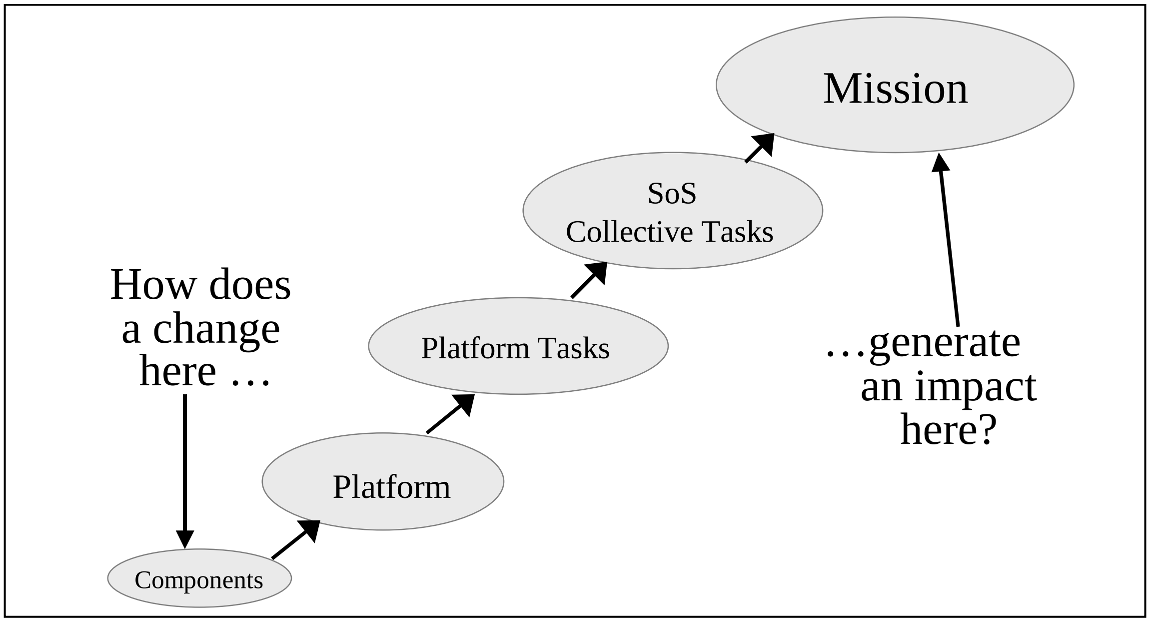

Figure 7. Impacts of Level 2 component state changes on Level 4 mission.*

To design a cost-effective LFT&E program, planners must ascertain what data are required by system evaluators for assessment decisions (i.e., required data set) relative to ballistic interactions and compare that required data set to the subset of reliable and relevant data available. The subset of data required for assessment that is unavailable or unable to be relied upon is identified as the data voids. With consideration given to the limitations in available resources, the data voids must be prioritized and addressed in the design of the LFT&E program (Nelson, 2000).

The MMF provides the foundation for identifying the required data set and data voids to be addressed in elements of the LFT&E program. Specific to LFT&E, MMF provides the basis for (1) the identification of critical issues to be addressed in LFT&E, (2) the design of LFT programs to address prioritized data voids, and (3) the design and execution of the evaluation process, in which the results of LFT are considered along with the results of other program supporting activities (i.e., M&S, CDE, etc.) with the objective of determining the consequences of the effects of ballistic interactions on mission tasks and related DOTMLPF. The MMF plays an important role in the LFT&E activities found in the shaded areas of figure 8. The following section provides a comparison of traditional platform-centric LFT&E strategies and MMF-based SoS task-focused LFT&E strategies.

*Figure modified from Tanenbaum and Bray (2005).

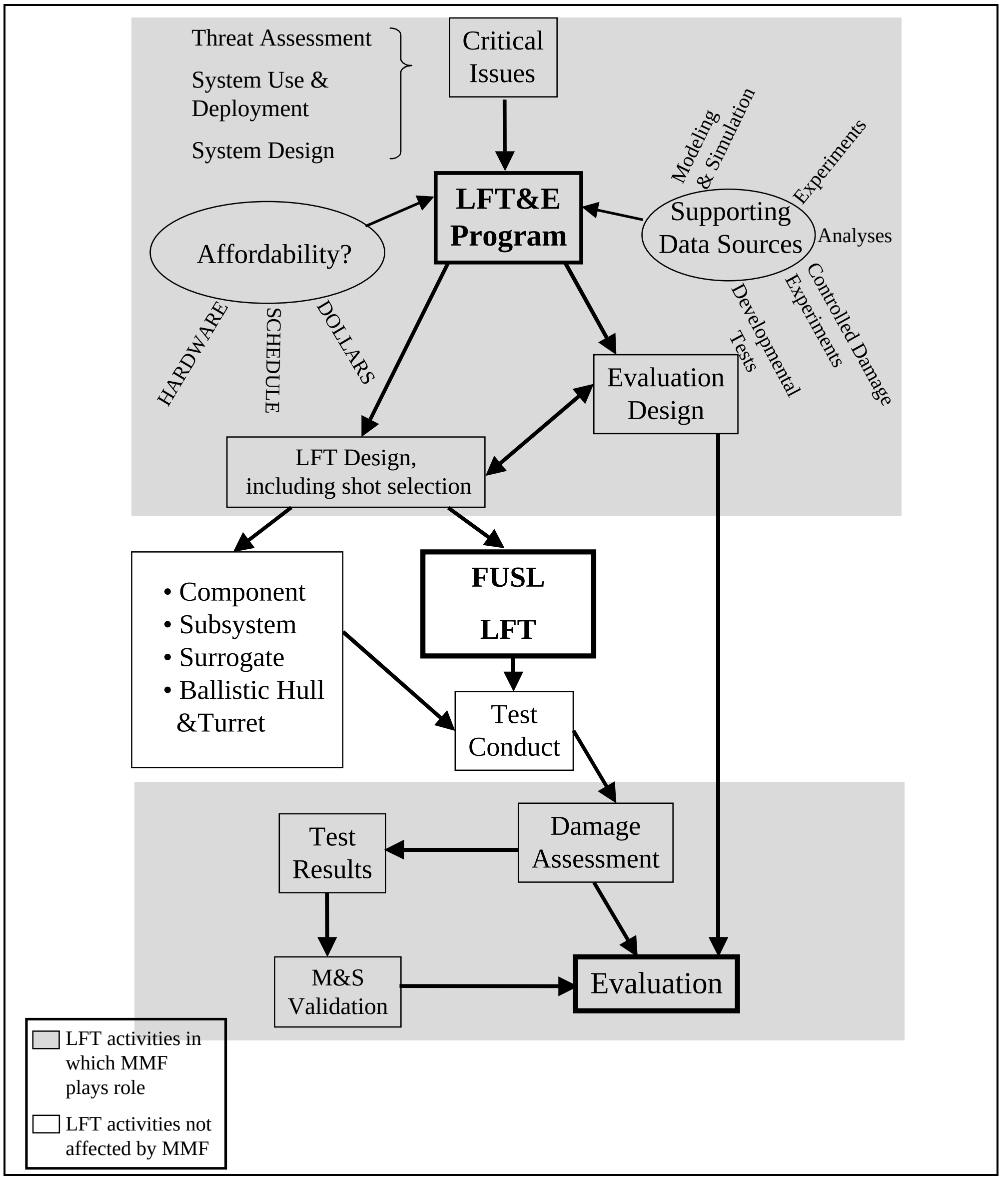

Figure 8. LFT&E activities in which MMF plays an important role.

3.2 Comparison of Traditional and MMF-Based LFT&E Strategies

Table 1 illustrates three major areas in which the traditional platform-centric LFT&E strategy is expected to differ from the proposed MMF-based SoS task-focused LFT&E strategy: Critical Issues, Shotline Selection, and Damage Assessment.

3.2.1 Critical Issues

Typically, traditional vulnerability platform-centric strategies have addressed three critical issues: (1) the vulnerability of the platform and crew/passengers to current and expected future perforating and nonperforating threats, (2) the effectiveness of vulnerability reduction measures,

Table 1. Comparison of traditional and MMF-based LFT&E strategies.

	Traditional Platform-Centric LFT&E Strategy	**MMF-Based SoS Task-Focused LFT&E Strategy**
Critical Issues	**What is the vulnerability of the platform to** current and future threats identified by the intelligence community? • What are the major causes of crew and passenger casualties? • What are the vulnerabilities of the platform to perforating and non-perforating threats? • What is the remaining platform mission utility after the shot? What vulnerability reduction measures are effective in reducing crew, passenger, and system vulnerability? How effective is BDAR in restoring **the platform to functional capability** after an attack?	**What is the reduction in the ability of the SoS to prosecute typical* missions after damage from** current and future threats identified by the intelligence community? • What are the major causes of crew and passenger casualties? • What are the vulnerabilities of the platform to perforating and non-perforating threats? • What are the remaining platform capabilities after the shot? What vulnerability reduction measures are effective in reducing crew, passenger, and system vulnerability? How effective are BDAR **and other maintenance actions** in restoring **SoS capabilities critical to mission prosecution** after an attack?
Shotline Selection	Platform: based on technical risk associated with the inability to determine **platform capability** as the result of ballistic damage. Crew: based on technical risk associated with the inability to predict injury to crew and passengers.	Platform: based on technical risk associated with the inability to determine the **effect on mission prosecution caused by loss of platform capabilities** as the result of ballistic damage. Crew: based on technical risk associated with the inability to predict injury to crew and passengers
Damage Assessment	Platform: • Determine damage to components and subsystem loss of function. • Map to **remaining combat utility via DAL or other $O_{3,4}$ construct.** Crew: • Determine casualties among crew and passengers. • Map crew incapacitation to **remaining combat utility via DAL or other $O_{3,4}$ construct.** BDAR: Determine expedient repairs that can be made to restore platform **to some level of combat utility**.	Platform: • Determine damage to components and subsystem loss of function. • Map to **remaining SoS capabilities by analysis and operational-type tests.** Crew: • Determine casualties among crew and passengers. • Map crew incapacitation to **platform loss of capabilities and confirm remaining SoS capabilities by analysis and operational-type tests.** **Mission Damage Assessment and Repair:** BDAR: Determine expedient repairs that can be made to restore **some platform capabilities during and immediately following an engagement.** **Other maintenance procedures: Conduct further repair to anticipate future mission engagements.**

*LFT&E considers all known and anticipated threats and uses of the platform. Unable to examine all scenarios, LFT&E focuses on those most likely and those of high interest to decision-makers. One outcome of this is that threats likely to be encountered now or in the future in the selected scenarios can be emphasized. Currently, the LFT&E strategies tend to consider all threats that are likely to be encountered in any scenario. The MMF provides a basis for scenario prioritization in the identification of critical issues.

and (3) the effectiveness of BDAR in platform restoration. An MMF-based SoS task-focused strategy addresses the same three critical issues, but from a different perspective than that of the traditional platform-centric strategy.

The traditional platform-centric strategy focuses on the extent to which a platform retains battlefield combat utility (Level 4) or a general ability to complete missions likely to be assigned to the platform when subjected to current and expected future threats. The platform is considered autonomous, and little consideration is given in the critical issues to the complementary capabilities of other platforms that are part of the SoS or to the platform's role in the completion of tasks that are linked to specific missions in the joint environment.

In contrast, the MMF-based SoS task-focused strategy focuses on the capabilities of the platform within the context of the SoS (Level 3) and the extent to which damage to the platform from current and expected future threats affects the SoS's ability (Level 3) to complete specific mission tasks (Level 4).[*] Redundancies and interdependencies among SoS platforms are considered in the identification of critical issues and prioritization of data voids.

In principle, there is no difference between the two strategies in their approach to identifying the vulnerabilities of the platform to perforating and nonperforating threats. The platform is the most basic element of an SoS from an LFT perspective. Thus, it is necessary to understand and quantify the effects of damage on component operation and subsystem function whether the focus is the single platform or the SoS and its mission tasks. The technical risk associated with the uncertainty of the threat effects on some components and subsystems, however, may be different for the MMF-based SoS task-focused strategy with its SoS perspective (see Shotline Selection, section 3.2.2).

Both strategies are concerned with crew and passenger survivability, which encompasses the susceptibility of the crew and passengers to injury from all insults.[†] Personnel survivability commands high priority regardless of mission considerations, and both strategies consider the identification of the major causes of crew and passenger casualties and the evaluation of the effectiveness of personnel protection measures as critical issues.

In a traditional platform-centric strategy, the LFT&E BDAR focus is on restoring as many platform capabilities as possible to give the commander further use of the vehicle in its intended or alternate role, depending on damage. For example, LFT of combat platforms has generally been conducted in the context of a 10 or 15 minute firefight.[‡] BDAR assessments have been

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[*] The MMF links tasks of specific missions (Level 4) to the capabilities (Level 3) that are required to complete those tasks. A task may be completed by a single platform or a group of platforms.

[†] From an LFT perspective, this often involves armor protection and fire/explosion if there are on-board combustibles.

[‡] Traditionally, Army armored fighting vehicles (AFVs) in close combat were analyzed in terms of their ability to continue or escape from an engagement lasting 10 or 15 minutes. Other timeframes have been used for other types of engagements (e.g., interdiction missions) and for other types of ground mobile vehicles, such as trucks and air defense systems. Army helicopters were analyzed in terms of their ability to continue controlled flight long enough to land, return to base, or continue the mission.

performed to determine whether the crew could effect sufficient repairs to continue the mission, to escape, or to make the platform available for an alternate mission through restoration of some of its capabilities.

With its emphasis on SoS mission tasks, the mission damage assessment and repair of the MMF-based SoS task-focused strategy may extend beyond the activities associated with traditional platform-centric BDAR to include a more extensive plan for assessing and repairing battle damage and other failures. For longer duration complex missions in which the platform may be involved in several engagements, conventional repair processes may be available to effect more complex repairs, restore platform capabilities needed later in the mission, and even repair reliability failures or nonballistic combat damage (see section 3.2.3 for additional discussion).

3.2.2 Shotline Selection

Shotlines in an LFT&E program are selected with the objective of minimizing the technical risk associated with the inability to predict platform capability and crew/passenger casualties following ballistic interactions. Shotline selection may differ between the traditional platform-centric and MMF-based SoS task-focused strategies in cases where data voids are related to the platform (vs. data voids related to personnel safety).[*] Shotline selection differences would reflect the distinction between the MMF-based SoS task-focused strategy focus on SoS capabilities and the traditional platform-centric strategy focus on the functional capability of the autonomous platform.

With limited time and dollars to devote to LFT, shotline selection requires the prioritization of identified data voids—areas in which there is little understanding of the effects of ballistic interactions on platform capabilities. In the MMF-based SoS task-focused strategy, the limited LFT shots must be “spent” to address the most urgent questions of a platform’s ability to support the SoS mission tasks. The technical risk associated with failing to address less critical capabilities in an LFT may be acceptable, however, particularly if some data are available from component tests or other sources.

Consider the following examples of two platforms, each with significant firepower capability—an armored personnel carrier (APC) equipped with an autocannon and a main battle tank (MBT). The role of the autocannon on the APC is to provide self-defense and covering fire for dismounted troops and to attack targets of opportunity. From the perspective of the commander assigned typical missions, the APC’s firepower may be of secondary importance, because the primary capability of the APC is mobility for troop transport. The APC would generally operate with other platforms in accomplishing its primary role, and any necessary firepower could be provided by companion vehicles.

[*]All LFT&E strategies would be expected to give a high priority to the investigation of data voids relative to potential crew and passenger casualties.

In both the traditional platform-centric and MMF-based SoS task-focused strategies, critical issues would include the vulnerability of the autocannon, related fire control, target acquisition, and ammunition handling subsystems. In the MMF-based SoS task-focused strategies, however, the technical risk associated with relying on modeling or previously generated and partially applicable data from other systems relative to firepower issues may be acceptable. Devoting precious LFT shots to mobility and crew survivability issues, which are of more interest from a mission prosecution perspective, might be a better investment and, overall, of less technical risk.

In contrast, the tendency in traditional platform-centric strategies would be to devote some shots to the firepower capability because the critical sub-issues tend to consider all platform capabilities equally important.*

In the second example, the MBT, however, not much difference would be expected between the two strategies in shotline selections. Providing mobile firepower is essentially the only reason an MBT is fielded. Thus, it would be reasonable in both strategies to devote LFT resources to develop a solid understanding of the vulnerability of the main gun, mobility subsystems, and supporting subsystems.

3.2.3 Damage Assessment

The objectives of damage assessment following ballistic interactions in both the traditional platform-centric and MMF-based SoS task-focused strategies are to identify (1) platform component damage and loss of subsystem function, (2) crew/passenger casualties, and (3) expedient repairs for platform restoration.

In the traditional platform-centric strategy, component damage and subsystem loss (Level 2) are mapped to combat utility (Level 4) through the use of an operations research mapping tool, such as the DAL. In the MMF-based SoS task-focused strategy, however, the focus is the capabilities of the platform within the context of the SoS (Level 3) and the ability to complete SoS mission tasks. Mapping component damage and subsystem loss of function to the SoS remaining capabilities requires analysis and operational-type tests.† The remaining capabilities following an LFT can be determined in laboratory settings. Quasi-operational tests using companion vehicles can be used to confirm the usefulness of residual capabilities within the SoS construct or to develop and validate “workarounds” to complete mission tasks with capabilities remaining within the SoS (i.e., damaged platform plus companion platforms).

Consider the following example. With the traditional platform-centric strategy, it is common practice to catalog the damage to platform components after the LFT firing, determine their remaining functionality, and assess the remaining functionality of the subsystems containing the

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*It is recognized that in the traditional platform-centric strategy, more shots may be devoted to certain specific capabilities because our knowledge of the vulnerability of those capabilities is less than for others.

†Crew incapacity would be mapped first to platform loss of capabilities and remaining platform capabilities. The results of this mapping would be incorporated into the laboratory and quasi-operational tests described.

damaged components. Determining the remaining subsystem functionality has generally been done in a laboratory setting, that is on the LFT pad, on a mobility test course, or at another fixed site where there is no attempt to replicate tactical settings or operations. In a laboratory setting, vehicles have been driven on a test track to determine limits of mobility, guns have been fired, and radio transmission or reception tests have been made using other vehicles located at specific distances from the tested vehicle. While these tests are useful for determining degradations in platform capabilities, they seldom give evidence of the significance of the loss of platform capabilities from a mission perspective or indicate whether some “workaround” can be devised. Unit-level or force-level models are typically used to assess significance, but seldom is there experimental verification. Further, in these simulations, the engaged system is considered either fully functional or killed in the context of Level 4 combat utility metrics. For example, a platform with damage to the main gun is considered to have either full firepower or no firepower at all. Seldom is a partial loss of system capability considered.

In an MMF-based SoS task-focused strategy in which the critical issues focus on the platform’s contribution to SoS mission task completion (i.e., vs. a focus on the capabilities of an autonomous platform), there are likely to be instances where it is of paramount importance to determine the significance of the degradation or loss of certain platform capabilities within specific mission settings. Quasi-operational tests in which one or more SoS companion vehicles operate in a tactical setting with the damaged vehicle in accordance with appropriate doctrine, tactics, techniques, and procedures could help determine whether the degradation or loss of a specific capability or combination of capabilities seriously threatens mission success. Such a test could also be used to investigate the viability of “workarounds” to accommodate the weaknesses of the tested platform. For example, can a companion vehicle provide total or partial active protection system support to a platform that can neither track nor fire upon incoming munitions?

Finally, in the traditional platform-centric strategy, an important part of the damage assessment process is identifying the expedient repairs that can be made to restore the platform to some level of combat utility. The BDAR process is essentially the same for the MMF-based SoS task-focused strategy, except the focus is on restoring platform capabilities that are needed to complete current mission tasks. As noted in section 3.2.1, the complexity and length of current combat missions in the SoS environment require more than BDAR to support long-term repair considerations. That is, mission damage assessment and repair assessments in LFT&E programs could provide insights into achieving complex repairs of components and subsystems damaged in combat through BDAR, as well as insights into accomplishing incremental repairs as the mission progresses through the use of other maintenance processes.

One possible approach is the development of methods (by either the crew or field repair units) to identify potential repair complexities induced by the ballistic attack and the parts and skill requirements needed to effect extensive repairs of those components. For instance, although it may be a rather simple matter to replace a black box, ballistic damage to the sheet metal, the attachment fittings, etc., could make replacement of the box much more difficult. Thus, the need

to make ancillary repairs of extensive ballistic trauma increases the overall scope of the repair and requires specific parts and skills to effect the black box replacement.

Insights gathered through MMF-based LFT mission damage assessment and repairs are useful in repairing and restoring platform capabilities degraded as the result of a spectrum of stimuli, including nonballistic events and normal wear and tear over time. The MMF taxonomy and V/L models under development provide a framework for considering (1) the effects of degradation of components from all causes (e.g., reliability failure, in addition to ballistic damage) on the platform capability to complete mission tasks and (2) the ability of the unit to repair or restore lost capabilities through expedient repair as provided through BDAR or through the field replacement of components in other maintenance actions.

4. Cost-Effective LFT&E

A structured process for building cost-effective vulnerability assessment strategies and vulnerability LFT&E programs, based on the MMF, is discussed in this section. The described process assumes (1) an LFT&E program (with FUSL LFT in the absence of a waiver) is mandated for a single platform that is part of an SoS and (2) operational requirements for the platform have established the minimum levels of capabilities required of the platform (as part of an SoS) to complete tasks linked to specific missions in realistic combat scenarios of the joint environment. Two very important considerations in establishing a cost-effective LFT&E program are the risks and costs associated with the assessment process.

4.1 Identifying the Risks in Vulnerability Assessment

Certainly, an important objective of vulnerability assessment is to minimize the likelihood that a significant vulnerability (i.e., vulnerability resulting in personnel casualties, catastrophic loss of the system, or failure to complete mission tasks) will remain undetected in a fielded platform, despite the actions taken during the acquisition process by the contractor, the Project Manager Office (PMO),[*] the T&E Working-level Integrated Product Team (T&E WIPT),[†] or the independent testers and evaluators. The risk associated with this likelihood, a vulnerability assessment risk, has three elements: the inherent risk, the control risk, and the detection risk (see figure 9).[‡]

[*]The PMO has the "responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs (DOD Directive 5000.1, p. 2 [2003]).

[†]A WIPT consists of headquarters and component functional personnel who support the materiel developer and focus on a particular such as T&E. The T&E WIPT is a subgroup of the Integrating Product Team and produces both the T&E Strategy and the T&E Master Plan (TEMP) for the weapon system (Army Regulation 73-1, p. 60 [2004]).

[‡]Risk terminology is borrowed from a financial auditing context, although use of terms is not strictly analogous to the terminology in auditing contexts.

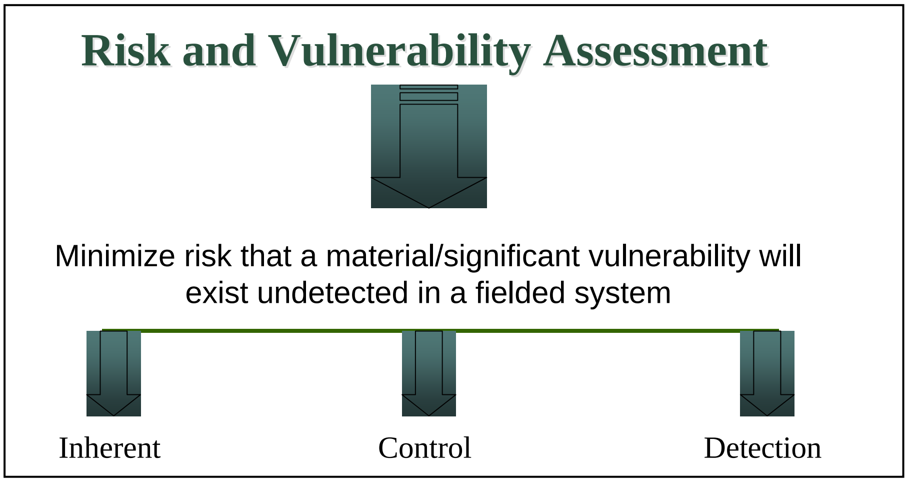

Figure 9. Three elements of vulnerability assessment risk.

The three elements of vulnerability assessment risk can be described as follows:*

Inherent risk is the susceptibility of the weapon system to material or significant system and personnel vulnerabilities. Assessing the level of inherent risk associated with a system requires an understanding of the environment in which the system must function, the expected mission(s) of the system and the tasks required to ensure mission success, the threats the system is likely to encounter, and the potential mitigating effects provided by other platforms of the SoS and the tactics and doctrine of the system users. Information relevant to the vulnerabilities of similar models or prior models of the same system, the complexity of the design of the system, and the impact of technological developments on the system serve as input to the assessment of inherent risk.

Control risk is the risk that a material or significant vulnerability will not be prevented or detected in analyses and tests conducted during the design and production phases of the system under the supervision of the PMO. An accurate assessment of the level of control risk associated with a weapon system requires an analysis of the elements of the PMO-directed survivability/ vulnerability assessment program (e.g., design and engineering analysis, experimental testing, inspection during production, etc.) and the critical data voids addressed by this program.

Detection risk is the risk that a material vulnerability will not be discovered by analyses, T&E, or other activities conducted prior to fielding of the system by sources independent of the manufacturer/contractor(s) and PMO. The level of detection risk is managed to a great extent by the independent system testers and evaluators who, having considered the levels of inherent and control risk associated with a system, determine the nature, timing, and extent of the additional analyses, tests and other activities (including LFT&E) to be performed prior to full-rate production and fielding.

*Adapted from material presented in Nelson (2000).

4.2 Weighing the Costs of Vulnerability Assessment

In fielding a system in which the survivability and vulnerability of the system and its crew are major concerns, control costs related to vulnerability assessment must be weighed against failure-to-control costs (see figure 10).*

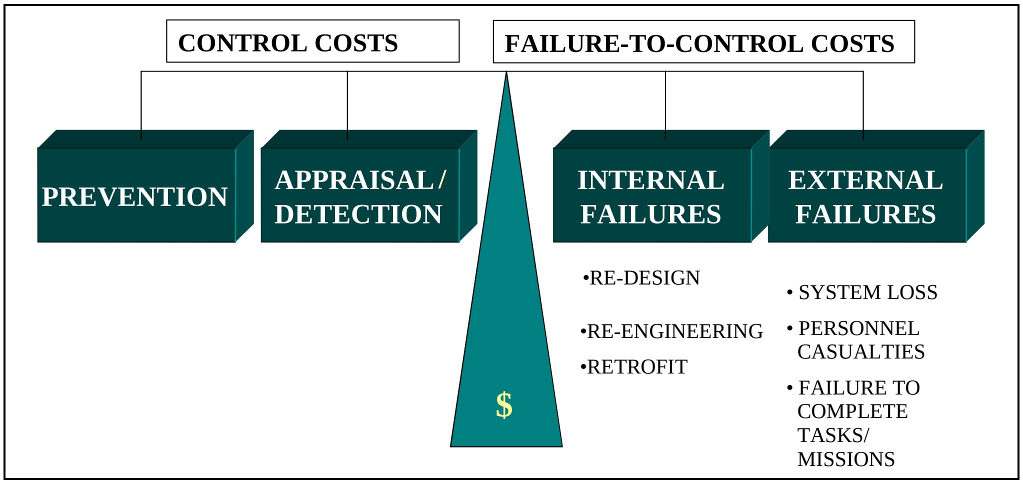

Figure 10. Balancing control costs against failure-to-control costs.

Control costs, categorized as prevention costs and appraisal/detection costs, are those costs incurred in the design, design analysis, and T&E phases of a system with the objective of eliminating or reducing the presence of vulnerabilities in the system. Prevention costs are incurred prior to and during the production process to plan for and ensure the expected level of conformity among mission needs, operational requirements, design specifications, and the actual system produced.†

Appraisal/detection costs are incurred to identify any nonconformity of the system in production or the completed system to the design specifications, operational requirements, and missions' needs prior to fielding of that system. Appraisal/detection costs include the costs of LFT&E in which the system is tested against threats likely to be encountered in realistic combat scenarios.‡

Failure-to-control costs, specifically internal failure costs and external failure costs, are costs associated with any vulnerabilities that are discovered after production is completed. Internal failure costs include the costs of system or component redesign, engineering changes, and retrofit—costs that result from addressing a vulnerability discovered after production of the system but before the system is fielded. External failure costs are related to vulnerabilities

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*In a manufacturing context, the terms "control costs" and "failure-to-control costs" refer to costs incurred in quality control in which the objective is the minimization of defects in products manufactured and the satisfaction of users' needs.

†Methodology assumes that operational requirements for a system have been established on the basis of the capability levels needed for mission task completion.

‡It is acknowledged that realistic threats employed in LFT&E might include overmatching threats or threats not considered at the time operational requirements were established.

discovered in the system after fielding and include the significant losses associated with personnel casualties, weapon system damage or destruction, and the failure of the SoS to complete the tasks that contribute to the prosecution of the mission in the joint environment.*

In general, the *total* sum of prevention costs, appraisal costs, internal failure costs, and external failure costs decreases with increased attention to control activities. An increase in control activities (i.e., design analysis, inspection and testing prior to full rate production) often results in an increase in internal failure costs (i.e., the costs to eliminate or reduce the vulnerabilities discovered in control activities)† and a much larger decrease in the very significant costs associated with external failures.

The very nature of external failures and the costs attached to them motivate decision-makers to consider and invest both time and money in control activities, such as LFT&E. In the current world of limited resources and constrained defense budgets, it becomes important to design an LFT&E strategy that insures that the data collected are relevant to the needs of those assessing system vulnerability and that the collection process is consistent and efficient, considering both time and costs incurred.

4.3 Identifying Data Required for Vulnerability Assessment in Ballistic Interactions

To conduct a cost-effective vulnerability LFT&E program, the LFT&E WIPT begins by identifying the data required by system evaluators for vulnerability assessment decisions (i.e., required data set) and the subset of data required for assessment that are unavailable or unable to be relied upon (i.e., data voids).

To identify the required data set for assessment decisions, a clear understanding of the objectives of vulnerability assessment is needed, as well as the assumptions made in describing the assessment methodology. The vulnerability assessment methodology defined in this report assumes that mission decomposition into lower-level tasks (possibly having a necessary start-completion ordering) has been completed, a relationship between the lower-level tasks and the minimum levels of system capabilities needed to complete those tasks has been established, and the platforms and SoS that provide the capabilities to complete the tasks have been identified. Part of the analysis in which capabilities are linked to platforms includes an identification of the redundancies and interdependencies among platforms within an SoS. The methodology also assumes that operational requirements for the platform have been established on the basis of the capabilities required for identified mission tasks that are part of realistic combat scenarios.

Given these assumptions, vulnerability assessment in LFT&E becomes an exercise in the evaluation of the extent to which the interactions of the identified platform and the ballistic threats the system is likely to encounter in combat result in personnel casualties (i.e., personnel

*Costs may be measured in nonmonetary (e.g., crew losses) as well as monetary (e.g., hardware destruction) terms.

†Failure to remedy vulnerabilities discovered in control activities, because of lack of time or resources, may also result in external failure costs.

vulnerability) and/or the failure of the system to retain the capabilities that were determined at the time of acquisition to be needed to complete specific mission tasks (i.e., system vulnerability). The operational requirements for the system define the minimum levels of those capabilities that must be retained by the system in combat for task completion in specific missions and provide the basis for determining the data required for the vulnerability assessment.

Assessment raises the question (see figure 11), "Will the OWNFOR platform (i.e., system assessed) deliver the minimum levels of capabilities identified as needed as part of an SoS and contribute to the completion of SoS collective tasks, given the interaction with likely combat threats?"[*]

The minimum levels of capabilities identified in the system's operational requirements are linked to specific tasks established in the decomposition of multiple missions. Given the minimum levels of specific capabilities needed to complete critical mission tasks (e.g., capabilities in areas of mobility, firepower, communications, etc.), analysts concerned with the assessment of vulnerability seek to identify the following relative to the OWNFOR system:

(a) Systems and subsystems that must be operationally functional (at partial or full level) to produce the minimum levels of capabilities needed for task(s) completion within the SoS.

(b) Critical components of the subsystems identified in (a).[†]

(c) Type of damage (i.e., personnel casualties, catastrophic loss of the system, damage to critical components of the system) to the platform expected from the interaction of the system within the SoS and OPFOR threats likely to be encountered in combat.

(d) Extent to which the system and its personnel are vulnerable, given the damage states identified in (c) and the critical components of the system identified in (b).

To provide the data described in the four preceding categories, the following activities grounded in the MMF are suggested:[‡§]

1. Define the set of initial configurations of the threat(s) likely to be encountered in combat and system just prior to ballistic interaction. This set of configurations selected considers the mission objectives, the physical, military, and civil environments of combat, location and time, and the users' DOTMLPF (Levels 5, 6, and 7).

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[*]In a similar manner, lethality assessment evaluates the likelihood that the OPFOR platform(s) is able to supply the capabilities at the minimum levels needed to complete the opposition's tasks, given the interaction of opposition platform(s) and OWNFOR munitions (i.e., system assessed).

[†]A system is composed of subsystems, and each subsystem is a set of components. Critical components are those components that if lost will result in a degradation of one or more subsystem functions, and consequently, a reduction in system capability (Roach, 1993).

[‡]Adapted from material presented in Nelson (2000).

[§]Similar data relevant to the OPFOR threat-target systems must be collected for lethality assessment.

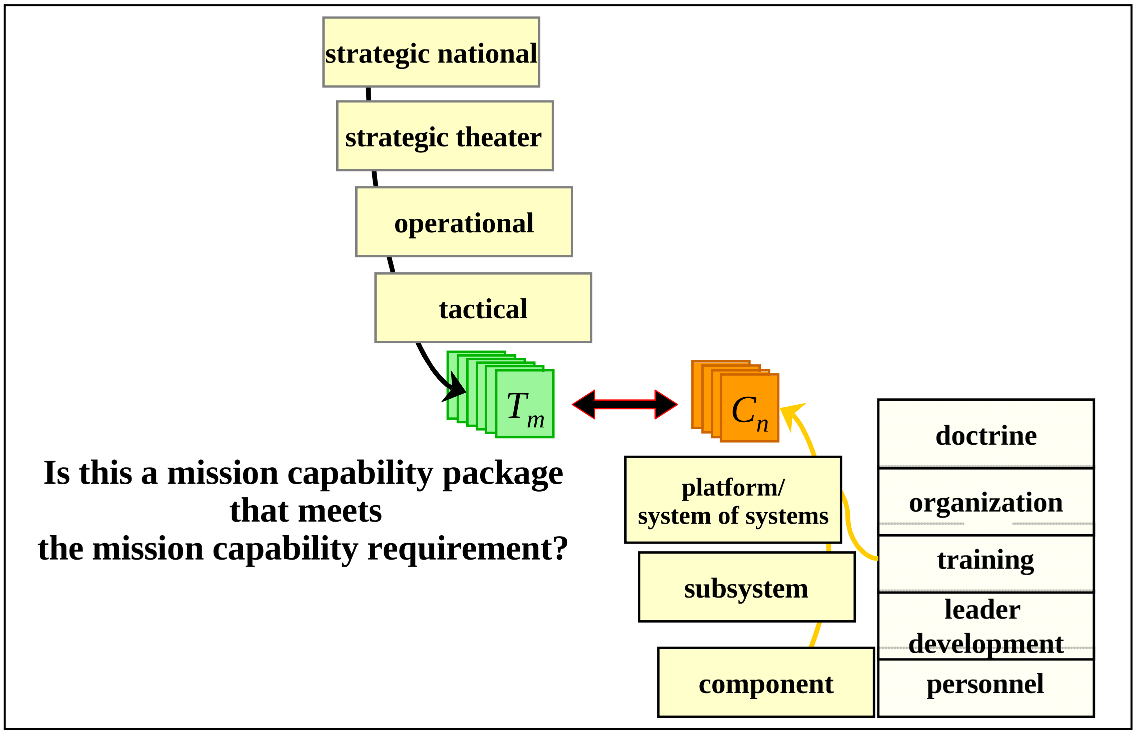

Figure 11. Assessing capabilities against mission/task requirements.*

2. Develop the damage operators expected in ballistic interactions of the system and threat. Consideration would be given to effects of ballistic penetration, including effects of fragment penetration and behind armor debris; air blast, ballistic shock, and ricochet phenomena; secondary and cascading damage; fire, toxic fumes, and fire suppression system; and multiple synergistic damage mechanisms. The damage operators establish the link(s) between the initial conditions of the threat and system prior to interaction (Level 1) and the damage state vectors of Level 2, representing the system's physical status following threat-system interaction.

3. Determine the specific *n-tuple* damage state vectors (Level 2) that are mapped from the specific points of ballistic threat-system interaction defined in Level 1. The *n* elements of the damage state vector describe the status (i.e., kill, no kill) of the *n* number of components of the system following a threat-system interaction. This activity also identifies potential for personnel casualties and catastrophic loss of the system.†

*Figure modified from Tanenbaum and Bray (2005).

†Personnel casualties may also affect the probability of mission completion (i.e., specific number of fully functioning crew members may represent a critical component of system).

4. Apply mapping operators or degraded state operators that establish the link(s) between the *n-tuple* damage state vectors (Level 2) that represent the damage states of the system following threat-system interaction and the *m-tuple* capability state vectors (Level 3) that represent the capabilities that remain following the interaction.

5. Compare the capabilities remaining following ballistic threat-system interactions (activity no. 4) to the capabilities needed for completion of mission tasks. Typically, capabilities required for task completion will be reported in terms of a Boolean expression, stating the logical conditions that must be met for mission task completion.[*]

6. Recognizing that system capabilities (Level 3) aggregate from subsystems and components, compare the specific components that are expected to remain in operation following the threat-system interaction (activity no. 3) to the specific critical components that must remain in operation to deliver the identified capability levels required for SoS task completion.[†] After considering redundancies and interdependencies among components and among systems in the SoS, this activity identifies component and subsystem vulnerabilities that may be critical to completion of mission tasks.

Data that are unavailable from reliable sources to complete these activities define the data voids, the subset of the required data set that is addressed in the LFT&E program. The LFT&E program is designed to fill the data voids identified by comparing the specific set of data required for assessment (required data set) to the subset of the required data set available from reliable sources. A cost-effective LFT&E program stresses the achievement of assessment objectives within the constraints of resources available.

4.4 Collecting Data Required for Vulnerability Assessment

Cost-effective LFT&E programs are designed with an optimal combination of component-level, subsystem-level, and system-level test data, with consideration given to cost, availability of hardware, and production schedule. The evaluation of the LFT results and data, as well as results confirming data from supporting program activities (e.g., M&S, CDE) must be presented in a format useful to decision-makers concerned with accomplishing mission tasks in the joint operating environment.

4.4.1 Establishing Data Voids in Required Data Set

The construction of an effective LFT&E program begins with a solid understanding of the links between Level 3 capabilities and Level 4 tasks. At this point, the decompositions of relevant SoS missions into lower-level tasks will have been completed, and the relationship between the

[*] This assumes that links have been established between the specific tasks identified in the decomposition of multiple missions and the capabilities required to complete those tasks. It is expected that required capabilities will vary among tasks, many tasks will require multiple system capabilities, and that expressions of capabilities required to complete tasks will often be written in terms of compound conditions (i.e., written with terms of “and” or “or”).

[†] Degraded Capability State models that map component level state changes to platform-level capabilities and the ability to complete identified tasks are in the early stages of development.

identified tasks and the minimum levels of capabilities to be supplied by the platform will have been established ($O_{3,4}$ in figure 12). Therefore, assessment planning starts with the knowledge of both the minimum levels of capabilities required for specific task completion and the effects on the SoS tasks of multiple missions if capabilities fall below specific identified minimum levels.

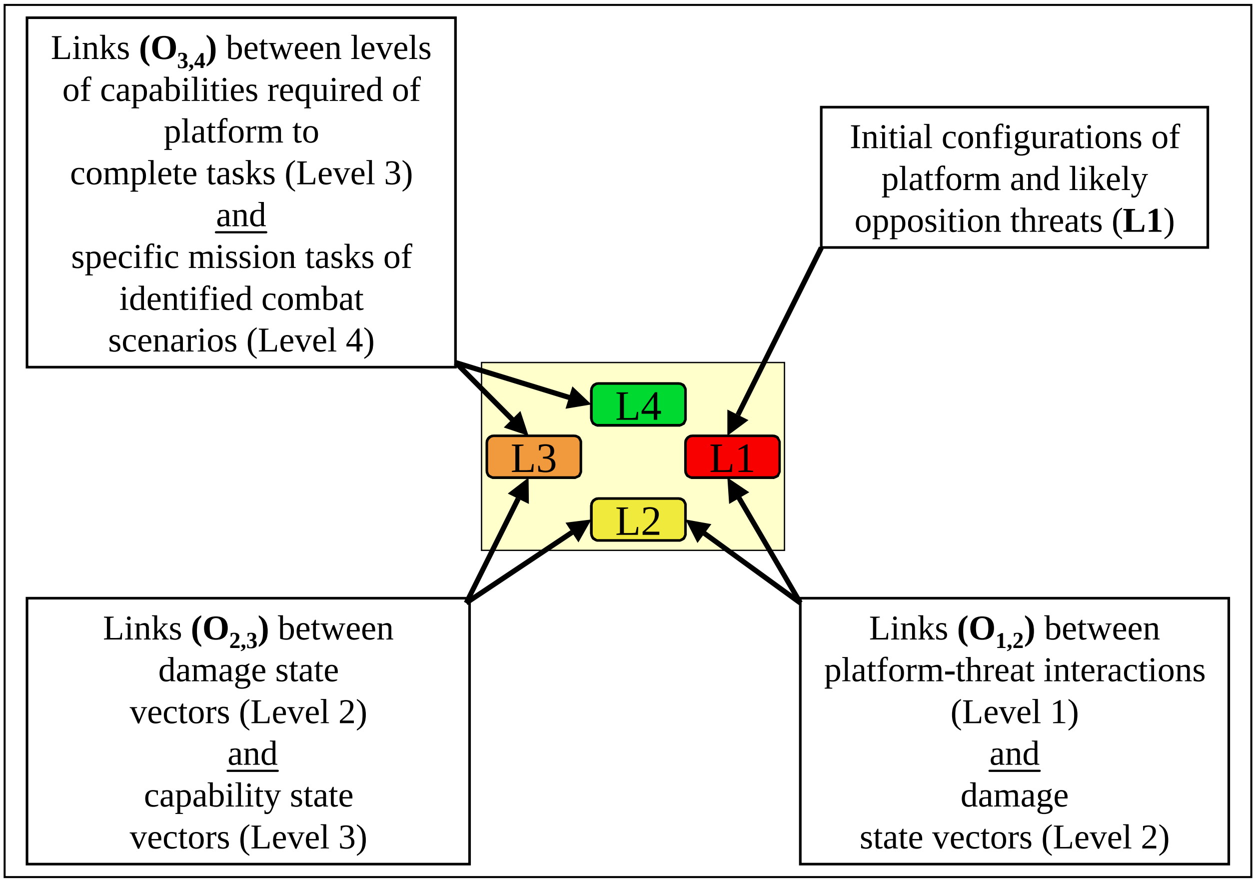

Figure 12. Required data set for vulnerability assessment.

To conduct the six activities, described in section 4.3, that complete the assessment objectives, the following data are needed: (1) data relevant to Level 1, the initial configurations of system and likely opposition threats; (2) data linking points of system-threat ballistic interaction to damage state vectors ($O_{1,2}$ in figure 12); and (3) data linking damage state and capability state vectors ($O_{2,3}$ in figure 12). To supply the required data, analysts collect the following types of data from defense databases, including data from other military services; system contractors; and defense analysis, testing, and evaluation agencies:*

- Combat data relevant to damage mechanisms, system damage, and residual capabilities of system as associated with the identified threats.

*Some data sources are from Army Regulation 73-1.

- Results of prior tests of materials, components, and subsystems of earlier and current models of the system or earlier or contemporary models of systems with similar technologies.
- Results of prior system-level tests of earlier models of the system or earlier or contemporary models of systems with similar technologies.
- Advanced technology and concept technology demonstrations.
- Force development tests/experimentations.
- Warfighting experiments.
- Design analyses of the system with consideration given to the new materials and technologies incorporated into the system.
- Engineering analyses and controlled damage experiments.
- Failure modes, effects, and criticality analyses (FMECA).
- Modeling and simulation runs that incorporate the system description, threat characteristics, and damage mechanisms expected in threat-system interactions.
- Results of developmental, operational, and production qualification tests.

If vulnerability assessment is begun early in the acquisition cycle, some of the data included in the required data set may be available from the preceding listed sources early in the design process of the vulnerability assessment strategy. Data not available or data for which analysts hold little confidence are identified as data voids and form the basis for the design of the LFT&E program.

4.4.2 Establishing Priorities Among Data Voids

In the design of the LFT&E program, limited resources dictate that not all data voids for all combat scenarios considered[*] can be explored and relevant data gathered. With data needs (i.e., required data set) linked to mission tasks through the MMF, decision-makers are able to understand more readily the risks of addressing and not addressing individual data voids. Data voids not addressed result in a level of uncertainty or risk related to completion of specific linked mission task(s). Consideration would be given to redundancies and interdependencies between systems within the SoS in establishing priorities.

Decision-makers need to determine what level of uncertainty is acceptable and adopt an appropriate methodology to prioritize data voids identified from the required data set. Several objective prioritization methods are available, such as the *Analytic Hierarchy Process* (AHP) or

[*] It is assumed that mission-to-task decomposition has been accomplished prior to the design of the LFT&E program on the basis of probable combat scenarios. Combat scenarios that are only remotely possible but are associated with costly losses may also be part of the analyses, if resources are available.

Quality Function Deployment (QFD),* but subjective prioritization of data by those with experienced domain-specific judgment is most often the approach employed.

4.4.3 Identifying Alternative Elements of LFT&E Program

A cost-effective strategy of vulnerability assessment begins at the Concept and Technology Development Phase and continues through the System Development and Demonstration and Production and Deployment Phases of the acquisition process. Elements of the LFT&E program may include coupon, component-level, subsystem-level, system-level, and FUSL LFT, as well as other activities (i.e., data sources) that support LFT, such as developmental and operational testing, M&S, design and engineering analyses, CDE, system integration laboratory experiments, and other activities that address the identified critical data voids relevant to assessment decisions.

Planning for vulnerability assessment early in the acquisition process may increase the number of options available to address the critical data voids and allow assessment activities to be completed at a time when design or engineering changes are more feasible and/or more economical. For example, in addressing some data voids in an LFT&E program, test articles, such as mock-ups or replicas, may be used in technical tests to gain insight into design and engineering issues, and these test articles are less expensive than the realistic test articles required in FUSL LFT. Other critical data voids (e.g., cascading and synergistic damage mechanisms), however, are unable to be addressed until later in the production process when the required hardware for testing becomes available.

The initial focus of an effective LFT&E program is the selection of plan elements that best address the identified and prioritized data voids. A vulnerability LFT&E program addresses those data voids concerned with the specific effects (e.g., ballistic penetration, air blast, ballistic shock, secondary and cascading damage) of platform-threat ballistic interactions on the identified platform's critical components, including its personnel.†

Figure 13 provides an illustration of the building blocks (e.g., FUSL LFT) of an effective LFT&E program. Construction of the program requires consideration of the (1) potential data sources or program elements (e.g., component-level LFT, CDE), (2) relevant ballistic interaction effects (e.g., fire, blast) that must be explored in vulnerability assessment, and (3) prioritized data voids relevant to critical components (e.g., identified as X and Y in figure 13).

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*A description of AHP and QFD and a discussion of the applicability of these tools to group decision-making can be found in references (Hauser and Clausing, 1998, pp. 68–73; Nelson, 1997; Saaty, 1994, 1995).

†Although LFT&E tends to focus on the effects of damage mechanisms on a platform's critical components, unexpected performance results (i.e., Level 3) have also been identified as the outcome of an LFT event. Unexpected performance consequences may result from the surfacing of an unanticipated damage mechanism, or, more typically, from an insufficient knowledge or understanding of an $O_{2,3}$ mapping relationship.

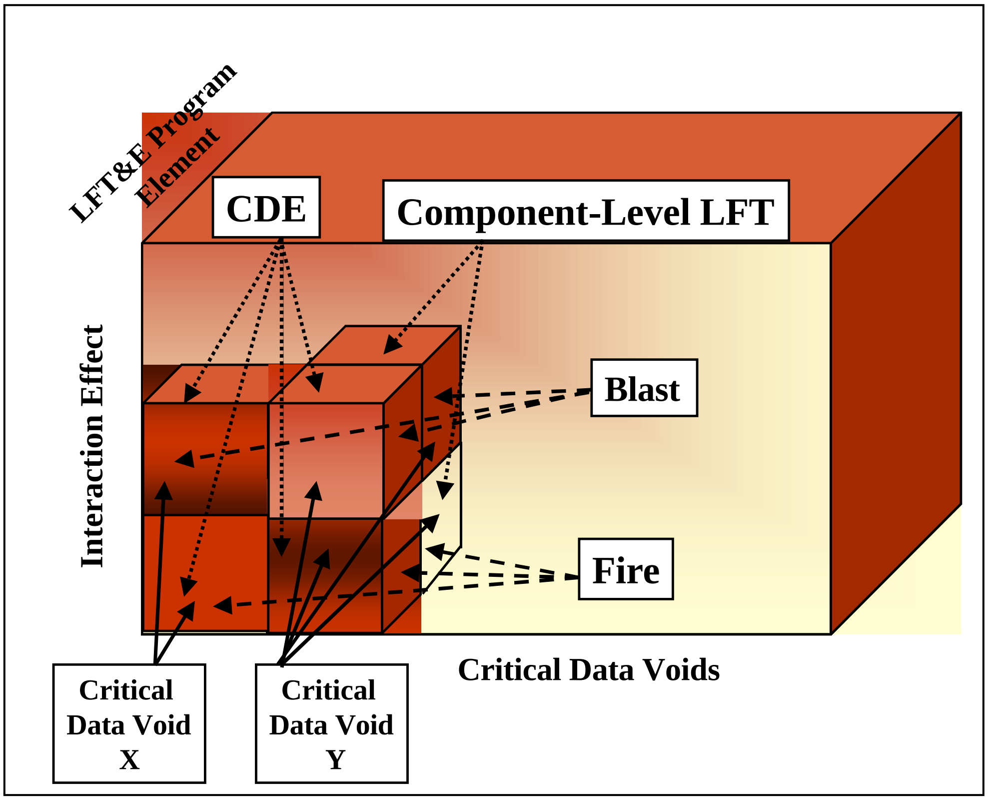

Figure 13. Choosing elements to address data voids in LFT&E program.

In choosing between alternative elements (i.e., elements that are able to address the same critical data void) to include in an LFT&E program, consideration is given to (1) the capacity of each element to address the critical/prioritized data voids, (2) the time constraints of the assessment schedule, (3) the production schedule and availability of system hardware, and (4) the costs attached to the execution of each element and the group of elements. Before adopting any one strategy, designers of the LFT&E program must consider the tradeoffs among the performance (i.e., capacity of elements to address data voids) of elements chosen, cost, and schedule, as well as the risk—that level of uncertainty associated with each element's capacity to provide the critical data within the time constraints of the assessment process at the identified cost—associated with the combined group of assessment elements.*

Identification of the individual elements of the LFT&E program and the activities that are conducted as part of each element is the starting point for both estimating the cost of an LFT&E program prior to plan implementation and/or computing and reporting the total cost of the program post-implementation.

*The cost methodology proposed in this report incorporates many of the characteristics of the Cost as an Independent Variable (CAIV) Methodology as explained in Nelson (2000).

5. Measurement and Reporting of Costs

Cost is an important consideration in both the design of the LFT&E program (i.e., elements selected for LFT&E program) and the design of the individual elements of the LFT&E program, such as FUSL LFT. A typical LFT&E program has a building block approach, beginning with coupon and component-level LFTs, proceeding through subsystem and system-level testing, and culminating in the FUSL LFT. In this section, the costs of FUSL LFT&E[*] are examined, but it is proposed that this methodology is equally applicable to the analysis of the cost of other elements of the LFT&E program. The identification and measurement of costs according to a consistent methodology is a requirement for valid comparison of alternative elements of an LFT&E program.

5.1 Implementation of Activity-Based Costing

The first step in computing the cost of FUSL LFT&E, an element of an LFT&E program, is the identification of the components or activities of FUSL LFT&E and the adoption of a methodology for the measurement of the costs of those identified activities. Activity-based Costing (ABC), a methodology that focuses on activities as the basic cost objectives, is suggested as an appropriate methodology to cost FUSL LFT&E.

Employing ABC methodology, the cost of FUSL LFT&E is determined by summing the direct material costs associated with FUSL LFT (i.e., costs of test assets) and the indirect costs of the resources consumed in the cross-functional FUSL LFT&E activities.[†]

Implementation of ABC in costing FUSL LFT&E requires the following:[‡]

- Identification of all direct materials used or consumed (i.e., test assets) in completion of FUSL LFT.

    Example: Direct materials include test articles, spare parts, munitions, and targets.[§]

[*]The cost of FUSL LFT&E includes the cost of the evaluation that follows the FUSL LFT. The evaluation is based on the data gathered in the FUSL LFT, as well as data from component-level and subsystem-level LFTs, analyses, experiments, M&S, and other relevant data-gathering activities.

[†]Direct costs typically include costs of materials and labor that can be traced in an economically feasible manner to a cost objective. Indirect costs are costs that cannot be traced to the cost objective in an economically feasible manner and must be assigned through an intermediary link that is identified by the cost methodology employed.

[‡]For a more detailed analysis of the costs of U.S. Army FUSL LFT&E activities, see Nelson (2000).

[§]Threats investigated could include gun-fired projectiles, missiles, rockets, and mines requiring a variety of launching/firing capabilities (DA Pam 73-1).

- Identification of all activities, as well as sub-activities, that consume resources in FUSL LFT&E.[*]

  Example: Activities in FUSL LFT&E include planning, M&S, execution of FUSL LFT, documentation of test results, and evaluation.

  The M&S activity includes the sub-activities of model extension/expansion to incorporate the test article, munitions, target(s) of interest, and damage mechanisms not previously included in the model, as well as improvements in damage mechanisms already part of the model; model verification and validation of existing models; exercise of model in preshot predictions and reruns of preshot predictions; and provision of full-view V/L estimates for use in evaluation.

- Identification of the type and quantity of each resource consumed by each sub-activity of each identified activity, as appropriate.[†]

  Example: Resources used in the test execution activity of the FUSL LFT on a test range include labor, equipment, and test range facility use. Data gathered for each sub-activity of the test execution activity include the hours worked by each specific level of skill required to complete the identified sub-activity, the type and pattern of use of the instrumentation employed,[‡] and the materials consumed by instrumentation or test range, as appropriate. Data relevant to materials and labor used in the protection of the environment and security of test assets, as well as in the repair of test assets, would also be collected.[§]

- Computation of the costs of all resources consumed by each sub-activity of an activity.

  Example: Cost of labor of personnel engaged in specific sub-activities of the test execution activity is computed by summing the respective products of estimated hours projected for each skill and average wage rate/hour established for the identified skill.

  Computation of the total cost of a sub-activity requires summation of the costs of all resources (e.g., labor, materials, equipment usage) consumed in that sub-activity.

- Computation of the total cost of each activity that consumes resources by summing the cost of all sub-activities identified as components of that activity.

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[*]In the context of ABC, the term “activity” is used to define the discrete unit of work for which costs are to be identified, and components of the activity are identified as sub-activities or tasks. In this report, the term “sub-activities” is used to avoid confusion with military “tasks,” the fundamental building blocks of missions.

[†]In implementation of ABC, not all sub-activities are identified and costed in detail, as explained in section 5.3.

[‡]Pattern of use describes how the equipment is used (e.g., for single FUSL LFT or multiple FUSL LFTs).

[§]Some materials used in repair of test assets may be classified and reported as direct materials, but other material repair costs may be classified and reported as part of the costs of the activities with which they are associated. Classification is related to ease with which cost can be traced to test asset.

- Computation of the cost of FUSL LFT&E element by summing the identified direct costs and the total costs of individual activities required for conducting FUSL LFT&E.

The advantage of employing ABC to cost the elements of an LFT&E program, as well as the individual activities and sub-activities of each element, is that ABC provides a means to weigh the value added against the costs incurred for each element, activity, and sub-activity. ABC affords the framework to identify elements, activities, and sub-activities that are non-value-added and are able to be eliminated as well as elements, activities, and sub-activities that are value-added but are able to be made more efficient. In other words, ABC allows a person to look at elements of an LFT&E program both from a strategic viewpoint, "Are we doing the right things?," and from an operational viewpoint, "Are we doing things right?" (Cooper and Kaplan, 1991).

Understanding an element's activities and sub-activity components, including the inputs and expected outputs of the activities, affords decision-makers an opportunity to monitor and manage the performance of the activities, consider the resources used in the completion of the activities, and to eliminate, redesign, and improve both activities and sub-activities contributing to those activities. Determining the cost of conducting an element of an LFT&E program, such as FUSL LFT&E, appears straightforward — implement an ABC system, compute the costs of the sub-activities of the activities of the element, and sum the costs of test assets and the identified sub-activities across activities. There are, however, some complexities in ABC implementation that must be addressed in the measurement and reporting of the costs of the test assets and the cost of the activities of an LFT&E program element such as FUSL LFT&E.

5.2 Complexities in Costing Test Assets

FUSL LFT test assets include the following: (1) the test articles (i.e., weapon systems tested), (2) the spare parts provided for the test articles, (3) the munitions fired (i.e., applicable to vulnerability tests), and (4) the targets fired upon (i.e., applicable to lethality tests) (Nelson, 2000).

5.2.1 Cost of Test Articles

The costs of test articles have been accounted for in various ways in completed LFT programs, and the total costs of FUSL LFT&E may be significantly affected by the choice of the alternative reporting value chosen for the cost of the test article(s).

Alternative reporting values for test articles used in FUSL LFT include (1) the cost of replacing the test article with an article identical to the original article (i.e., replacement cost), (2) the cost of returning the test article following FUSL LFT to its condition prior to FUSL LFT (i.e., restorative cost), or (3) the cost of acquiring the original test article (i.e., historical cost).

It can be argued that the restorative cost (i.e., the cost to return the test article to its original condition) is the most appropriate value to use to report the test article cost if (1) the test article is

in a salvageable condition following testing, (2) the restorative cost is able to be estimated, and (3) the restorative cost is the smallest of the three proposed alternative values. Regardless of whether or not the test asset is restored, the restorative cost is a cost of testing. If the restorative cost is higher than one or both of the remaining alternative values or the test article cannot be restored, it is suggested that the lower of the alternative values be reported as the cost of the test article.*

All available alternative values for costing the test article should be disclosed and made part of the database available to those budgeting for the FUSL LFT of future systems. The computations supporting reported values, including any amounts attached to these costs (e.g., engineering support costs), should be explained in full to facilitate the processing of this information in comparative analyses of assessment plans and in future budgeting activities.

5.2.2 Cost of Spare Parts

The cost of spare parts for the test articles needed in the execution of the FUSL LFT is not always easy to identify. For example, the contractor may agree to supply spare parts as needed for a fixed cost in a test system support package that is part of a larger contract, such as an LRIP contract. The attachment of the support package to the LRIP contract may make it difficult to report an accurate line item for spare parts. In other cases, spare parts may be supplied by the contractor, and a contract modification following the completion of the FUSL LFT accounts for parts required of the contractor during the testing phase. In still other cases, U.S. Army testers acquire parts from Army depots.

The cost incurred at the time of purchase (i.e., historical cost) is generally reported as the cost of spare parts, and the reporting of this cost should include a description of the contract agreement. Disclosure of the spare parts used vs. spare parts purchased and related costs may prove useful in planning of subsequent FUSL LFT events.

5.2.3 Cost of Munitions and Targets

Munitions used in lethality tests or targets used in vulnerability tests are often acquired in prior combat or in nonmonetary trades with other agencies. It may be difficult to obtain an historical cost or to estimate a replacement cost for the munitions used in lethality tests or the targets used in vulnerability tests. A complete accounting of the costs of test assets, however, would include, if available, (1) the estimated cost of the munitions/targets with the relevant range of values for that estimated cost or a disclosure of the inability to estimate the cost for identified assets, (2) the cost of transportation of targets to test ranges, and (3) the cost to repair target for intended use or repair following test use, if appropriate.

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*The term "restorative cost" is used to describe the limited situations in which a test asset is able to be restored to its original condition. If a test article is restored to less than its original condition, the test asset will likely not be fielded because of the potential weakness from the damage incurred in testing. The test asset cost may then be reported by the alternative replacement or historical cost less the net salvage value of the restored test asset (i.e., restored value less cost of restoring).

5.3 Complexities in Costing Activities

There are several questions that must be addressed prior to costing activities in the implementation of an ABC methodology. First, how is an activity defined? Most ABC authors agree that an activity requires a verb (i.e., action) and a noun (result) that characterizes the activity as a process, such as *conduct preshot predictions* or *participate in LFT&E WIPT*,[*] and must represent a significant level of expenditure (Brimson and Antos, 1994). Complexities arise, however, in defining the activity *breadth* and activity *depth* within an ABC implementation, such as in the costing of the activities of FUSL LFT&E.

In the implementation of ABC for the FUSL LFT&E element, activity breadth is identified by addressing the question, "What scope of activities should be included in the costing of FUSL LFT&E?" Defining the activity depth in ABC implementation provides answers to questions such as, "How much detail is required in costing task components of identified activities?" Delineating activity breadth and depth in ABC implementation requires an understanding of how decision-makers plan to use the activity cost data supplied by ABC analysis.

Assuming the purpose of ABC implementation is the production of reliable, comparable (i.e., across alternatives), and consistent (i.e., across periods) cost data for purposes of making strategic and operational decisions, it is helpful to identify activity breadth by categorizing the LFT&E program element's activities as *primary* or *secondary* relative to the decision-makers' proposed use of the ABC data. Primary activities would be defined as work efforts that are directly associated with the cost objective of decision-makers, and secondary activities as those that create the environment that allows the primary activities to be performed. Primary activities would receive priority in ABC implementation with secondary activities included if decision-makers' needs so dictated.

In reality, conducting a U.S. Army ground or air system FUSL LFT&E program results in activities in many agencies, including the Office of the Director, Operational Test and Evaluation (DOT&E), the Office of the Deputy Director, Operational Test and Evaluation, Live-Fire Testing and Missile Defense (DDOT&E [LFT]), the Office of the Deputy Under Secretary of the Army for Operations Research (DUSA [OR]), the Office of the Deputy Chief of Staff for Intelligence (DCSINT), the U.S. Army Medical Research and Materiel Command (MRMC), the U.S. Army Training and Doctrine Command (TRADOC) including the U.S. Army Ordnance Center and School (USAOC&S) and the U.S. Army Transportation Center and School (USATC&S), the U.S. Congress and its subcommittees, analysis groups utilized by the aforementioned offices (e.g., Institute of Defense Analysis), U.S. Army Developmental Test Command (DTC), U.S. Army Research Laboratory Survivability/ Lethality Analysis Directorate (ARL SLAD), Aberdeen Test Center (ATC) and other test centers, U.S. Army Materiel Systems Analysis

[*] The LFT&E WIPT, a subgroup of T&E WIPT, is formed to coordinate planning of LFT&E program. The group is chaired by the system evaluator.

Activity (AMSAA), U.S. Army Evaluation Center (AEC), and the PMO associated with the specific weapon system tested.

To make a valid comparison of the costs of LFT&E elements, decision-makers must be provided with cost data that are identified and measured according to a consistent methodology employed across assessment plans and elements of the plan. For each plan element, the breadth of activities and depth of sub-activities included in implementation of ABC must be identified. Table 2 shows one possible combination of the activities, sub-activities, and resources consumed in activities that may be selected for ABC implementation for the costing of FUSL LFT&E. As shown in this table, the breadth of implementation is defined by seven primary activities, and the depth is limited to the separate costing of sub-activities for three of the seven activities.

In addition, for each resource consumed, the methodology used in computing the cost must be described. Referring again to table 3, it can be seen that labor is a significant resource consumed in all FUSL LFT&E activities across all agencies. In accounting for the labor costs of employees engaged in activities in an agency, it is important to understand how that agency measures and reports its labor costs. For example, are overhead administrative costs of the employee's agency attached to direct labor hours? Are labor costs based on the actual hours worked or the hours estimated to be needed for the required service?

In situations in which there are alternative ways of measuring the costs of an activity, the measurement method employed should be identified and described. Allocated costs should be so identified, and the bases of allocation or the rates used in allocation should be fully explained. In addition, information that allows the decision-maker to compute the costs in an alternative manner should be disclosed. This allows uniformity to be established in reporting costs across systems, agencies, and periods.

5.4 Complexities in ABC Implementation for LFT&E Programs

Costing the elements of LFT&E programs, under an ABC methodology, requires a firm grasp of the activities and sub-activities that define the program's elements and reliable cost data relative to the resources employed in conducting those activities and sub-activities. Comparing the costs of LFT&E program elements conducted by different agencies requires the establishment of guidelines or standards for measurement and reporting of those costs.

Currently, the costs of the elements of the LFT&E programs, as well as the costs of the individual activities of the elements, are determined in conversations between the PMO, the LFT&E WIPT, and the agencies responsible for conducting the program element. For example, the costs of conducting M&S activities are identified in a dialogue between SLAD and PMO personnel. Some agencies engaged in LFT&E efforts use a variant of ABC to measure the costs of specific services performed by personnel of *that* agency. Although single agencies may apply

Table 2. Activities, sub-activities, and resources consumed in FUSL LFT&E.

Activity to Be Costed	Sub-Activities to Be Costed	Resources Consumed in Activity*
Meetings of LFT&E Working Integrated Product Team (LFT&E WIPT)	—	Labor hours of team members
Modeling and Simulation	Extension or expansion of existing models Verification and validation of models to be used in FUSL LFT&E Exercise of models in pre-shot predictions; reruns as needed Provision of full-view V/L estimates for use in the FUSL LFT evaluation	Labor hours of those engaged in extension, verification, and validation of models Labor hours of those engaged in exercise of models in pre-shot predictions Labor hours of those providing full-view V/L estimates Materials used in M&S, as needed
Development of LFT&E Event Design Plan (EDP)	—	Labor hours of lead in preparation Labor hours of other LFT&E WIPT members
Writing of Detailed LFT&E Test Plan (DTP)	—	Labor hours of tester/preparer of plan Labor hours of reviewer of DTP, when applicable
Performance of FUSL LFT	Setup and execution of FUSL LFT, including instrumentation Operation, maintenance, and repair of test assets; target repair and maintenance Battlefield damage and assessment and repair Damage assessment and casualty assessment	Labor hours of those engaged in: planning, training, setup, execution of FUSL LFT Labor hours of those engaged in preparation of test range, BDAR and damage and casualty assessment Materials (not test assets) & equipment used in FUSL LFT; materials used in protection of environment Test facilities used
Preparation of Documentation	Preparation of damage assessment shot records Preparation of detailed damage assessment report Preparation of detailed test report (DTR)	Labor hours of preparers of shot records, detailed damage assessment report Labor hours of lead in DTR and DTR contributors/reviewer
Preparation of the System Evaluation Plan (SEP) and Independent System Evaluation Report (SER) (FUSL LFT evaluation is a component)	—	Labor hours of preparers of SEP and SER

*Costs of facilities and equipment (including computers) used for completion of LFT&E and non-LFT&E activities may be allocated to LFT&E activities in full ABC implementation.

consistent accounting principles (e.g, rules for cost allocation) across platforms and periods in costing the sub-activities and activities performed by *that* agency, there is little uniformity in measuring and reporting costs across agencies and Services (Nelson, 2000). This lack of uniformity makes it difficult to compare the costs of alternative elements (i.e., elements completed by different agencies) considered in the design of LFT&E programs.

In addition, there is no common database that currently exists to collect LFT&E program cost data across single or multiple Services in a format that would be useful to test planners. The establishment of such a database would require the identification of:

- Specific data to be collected and reported (e.g., include only cost data that are the responsibility of the PMO[†]; include cost data for specific identified activities and sub-activities).
- Acceptable cost data sources to be used for costs reported.
- Acceptable methods for the measurement of costs, including the allocation of costs.
- Acceptable format for reporting data (e.g., level of aggregation of costs).

Contributors to the database would be required to:

- Report data according to guidelines provided and explain incomplete or missing data.
- Disclose cost measurement and allocation methods used, including bases for allocation, if alternative methods are acceptable.

The ability to share activity cost data across systems is one of the benefits of using the ABC methodology to cost elements, activities, and sub-activities of an LFT&E program. For example, the cost of performing a sub-activity that is common to the test execution activity of multiple platforms does not need to be recomputed for each system. Minor changes in the sub-activity from one platform to another (e.g., changes in wage rates) requires only minimal modifications to the initial cost computations made for the first system.

Identifying the costs of activities and sub-activities performed in the completion of LFT&E programs, the proposed data base would provide data useful for the:

- Building of cost estimation models for budgeting the costs of future LFT&E program elements.
- Assessment and improvement of the operational efficiency of LFT&E program elements, activities, and sub-activities.

[†]Thus, the costs expended by AEC in evaluation and the costs incurred by USAOC&S (other than travel, which is reimbursed by PMO) in BDAR analysis and participation in damage assessment would not be included.

- Design of more cost-effective LFT&E programs by weighing the value added against the costs incurred in completing LFT&E program elements, activities, and sub-activities. The ABC methodology allows the identification of the incremental costs incurred with the addition of specific test activities designed to address particular data void(s). Incremental benefits expected from additional tests would include a more complete understanding of platform vulnerability possibly leading to product modification or changes in military strategy.

6. The Way Ahead

This research effort builds on the work of two earlier studies, published by ARL, in which the impacts (i.e., costs, benefits, and risks) of LFT&E programs are addressed. The first publication (Deitz et al., 1996) reported the results of the SLAD/AMSAA effort to develop a methodology that would quantify the advantages and disadvantages of conducting FUSL LFT as an element of an LFT&E program.[‡] Deitz et al. (1996) reviewed the V/L process and V/L assessment models and discussed the merits and limitations of four different risk-benefit analysis methods, all in early stages of development.

The second ARL publication (Nelson, 2000) described the activities of the FUSL LFT&E of three different weapon systems, identified the cost components of those activities, and proposed the ABC methodology for measuring and reporting the costs of LFT&E programs. Contributions of FUSL LFT&E to a V/L assessment strategy were described, and suggestions for improving the cost-effectiveness of FUSL LFT&E concluded the report.

Although acknowledging the contributions of prior LFT&E programs in the areas of system design, personnel survivability, and development and validation of analytical models, this effort recognizes that the variety of threats and combat landscapes facing today’s warfighter and the increased sophistication of platforms operating within a system of systems context in an integrated and information-centric battlefield suggest the need for a new look at how LFT&E programs are conducted. Specifically, it identifies changes that might lead to a more efficient and effective LFT&E process, providing decision-makers with more relevant and reliable information for the dollars expended.

An MMF-based SoS task-focused LFT&E strategy is proposed to replace the traditional platform-centric strategy that emphasizes the functional capabilities of the autonomous platform. The MMF-based SoS task-focused strategy focuses on the extent to which the platform retains those capabilities needed for completion of SoS tasks and the ability of the SoS to complete current and future mission tasks in the joint environment.

[‡]The study, commissioned by Mr. Walter Hollis, the Army Deputy Under Secretary for Operations Research, was tasked to develop a methodology to improve the LFT waiver process.

The MMF provides the foundation for the identification of the critical issues and the design of the LFT program to address the prioritized data voids, as well as the design and execution of the evaluation. Consideration is given to redundancies and interdependencies between complementary platforms within the SoS, and the importance of communications across systems is recognized. The MMF-based SoS task-focused strategy provides the opportunity to use test assets (i.e., hardware, range time, and expertise) to address V/L issues of paramount importance to the unit's ability to complete its mission. Because the MMF provides a task-organizing process that links mission tasks, capabilities, and available resources, decision-makers are able to understand more readily the risks in specific scenarios of addressing and not addressing particular data voids.

Critical issues emphasize recoverability in the MMF-based SoS task-focused strategy, with the perspective now directed toward SoS operations in the joint environment. This new perspective would be expected to result in modifications to shotline selection and damage assessment, as the focus expands to include the long-term, as well as short-term, needs for SoS capabilities. It allows a realistic assessment of technical risk associated with foregoing test shots that may be of interest at the platform level but are not critical to understanding SoS effectiveness. In a roll-up of platform LFT program results to the SoS level, decision-makers are provided with a better grasp of the ability of the unit of operation to complete tasks to standards under given conditions and the risks associated with alternative courses of action. LFT results are analyzed and evaluated not only in terms of the platform and warfighter, but also in terms of network-enabled warfighting, information, and interoperability.

With consideration to the costs and risks associated with vulnerability assessment, a structured process for building cost-effective LFT&E programs in an MMF environment is presented. This process includes the identification and prioritization of data voids and the selection of the optimal program elements for addressing those voids, considering time, production schedule, hardware availability, and cost. ABC is proposed as the appropriate methodology for costing the individual elements and activities of an LFT&E program. ABC provides a framework for the decision-maker to view LFT&E program elements from both strategic and operational perspectives, addressing the respective questions, “Are we doing the right things?” and “Are we doing things right?” (Cooper and Kaplan, 1991). It affords the means for eliminating non-value-added elements and activities and seeking ways to make value-added elements and activities more efficient. There are, of course, complexities in ABC implementation, and suggestions for addressing those complexities are discussed.

Although not proposing modifications to the process of *executing* LFTs, the described methodology does propose significant changes to the process of planning for and evaluating the results of LFT&E programs. Implementation of a cost-effective MMF-based SoS task-focused approach to LFT would require:

- The integration under the MMF of the efforts of acquisition, requirements, M&S, T&E, and training communities within and across Services, achieved only through the support of top levels of defense administration.

- The allocation of resources to the appropriate Service divisions to ensure the availability of test assets, including hardware, testing facilities/ranges, and people with the levels of expertise needed for the planning and evaluation processes of the proposed LFT&E programs.

- The construction of platform operational requirements based on the capabilities needed for the completion of multiple tasks of multiple missions. This construction requires the definition of a set of platform-appropriate missions with links established between mission tasks and the levels of capabilities required to complete those tasks.[§] A significant challenge to this endeavor will be the definition of capabilities needed by a platform, as a component of an SoS, in scenarios in which some or all SoS components are operating at less than their full capacities.

- The identification and measurement of the costs of LFT&E elements, according to a consistent methodology that allows the value added in completing LFT&E program elements to be weighed against the costs incurred in conducting those elements.

Although implementation issues may appear daunting, there are efficiencies to be gained by the sharing of information between those responsible for the design of the weapon system, the assessment of system V/L, the training of system users, and the repair and maintenance of the system. Understanding the mission and associated SoS tasks is the basis for understanding how users rely on the platform—the foundation for building cost-effective acquisition, T&E, training, and maintenance programs. Currently, MMF models that link mission tasks to capabilities are in the early stages of development. These models are expected to provide a foundation for the construction of operational requirements for a system, as well as for the assessment of the V/L of that system operating within an SoS environment.

In conclusion, it is important to recognize the significance of the LFT&E program to the total T&E strategy. The objective of a T&E program is to facilitate the measurement and assessment of the effectiveness, suitability, and survivability of platforms relevant to their contributions to the SoS. It follows, therefore, that an LFT&E program needs to be designed and conducted to ensure the efficient collection of reliable, relevant data in a format that allows evaluators to assess the capabilities of the platform and the SoS, of which the platform is a member, to complete identified SoS tasks in tactically realistic scenarios following ballistic interactions. The MMF provides a valuable structure for both the design of LFT programs and the evaluation of LFT results.

[§]A sufficiently large and representative set of mission scenarios will be needed to satisfy operational requirements and T&E decision-makers, as well as the user community.

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List of Symbols, Abbreviations, and Acronyms

ABC	=	Activity-Based Costing
AEC	=	U.S. Army Evaluation Center
AFTL	=	Air Force Task List
AFV	=	Armored Fighting Vehicle
AHP	=	Analytic Hierarchy Process
AMSAA	=	U.S. Army Materiel Systems Analysis Activity
APC	=	Armored Personnel Carrier
ARL	=	U.S. Army Research Laboratory
ARL SLAD	=	U.S. Army Research Laboratory Survivability/Lethality Analysis Directorate
AoA	=	Analysis of Alternatives
ATC	=	U.S. Army Aberdeen Test Center
AUTL	=	Army Universal Task List
BCT	=	Brigade Combat Team
BDAR	=	Battle Damage Assessment and Repair
CAB	=	Combined Arms Battalion
CAIV	=	Cost as an Independent Variable
CDE	=	Controlled Damage Experiment
DAL	=	Damage Assessment List
DCSINT	=	Deputy Chief of Staff for Intelligence
DoD	=	Department of Defense
DOT&E	=	Director, Operational Test and Evaluation
DDOT&E (LFT&E)	=	Deputy Director, Operational Test and Evaluation, Live-Fire Testing and Missile Defense

DOTMLPF	=	Doctrine, Organization, Training, Materiel, Leader Development, Personnel, and Facilities
DTC	=	U.S. Army Developmental Test Command
DTP	=	Detailed Test Plan
DTR	=	Detailed Test Report
DUSA (OR)	=	Deputy Under Secretary of the Army for Operations Research
EDP	=	Event Design Plan
FMECA	=	Failure Modes, Effects, and Criticality Analysis
FCS	=	Future Combat System
FUSL	=	Full-Up System-Level
FUSL LFT	=	Full-Up System-Level Live-Fire Test
FUSL LFT&E	=	Full-Up System-Level Live-Fire Test and Evaluation
IPT	=	Integrated Product Team
JCIDS	=	Joint Capability Integration and Development System
JFC	=	Joint Forces Command
JLF	=	Joint Live-Fire
LFT	=	Live-Fire Test or Live-Fire Testing
LFT&E	=	Live-Fire Test and Evaluation
LFT&E WIPT	=	Live-Fire Test and Evaluation Working-level Integrated Product Team
LRIP	=	Low-Rate Initial Production
M&S	=	Modeling and Simulation
MBT	=	Main Battle Tank
MMF	=	Missions and Means Framework
MRMC	=	U.S. Army Medical Research and Materiel Command
MTP	=	Mission Training Plan
OPFOR	=	Opposing Forces
OPLAN	=	Operation Plan

OPORD	=	Operation Order
OSD	=	Office of the Secretary of Defense
OWNFOR	=	Own or Friendly Forces
PMO	=	Project Manager Office
QFD	=	Quality Function Deployment
SEP	=	System Evaluation Plan
SER	=	System Evaluation Report
SoS	=	System of Systems
T&E	=	Test and Evaluation
T&E WIPT	=	Test and Evaluation Working-level Integrated Product Team
TEMP	=	T&E Master Plan
TRADOC	=	U.S. Army Training and Doctrine Command
UNTL	=	Universal Navy Task List
UJTL	=	Universal Joint Task List
USAOC&S	=	U.S. Army Ordnance Center and School
USATC&S	=	U.S. Army Transportation Center and School
V/L	=	Vulnerability/Lethality
WIPT	=	Working-level Integrated Product Team

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ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
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11	DIR USAMSAA P DEITZ (6 CPS) E ATZINGER R THOMPSON A WONG D HODGE B PARIS
40	DIR USARL AMSRD ARL SL R SANDMEYER AMSRD ARL SL EM D BAYLOR AMSRD ARL SL BB R DIBELKA J PLOSKONKA D JORDAN G KUCINSKI M KUNKEL P KUSS G MANNIX P MERGLER J SHORT B WARD AMSRD ARL SL BD A DRYSDALE F MARSH R MOYERS L MOSS J POLESNE S POLYAK B SMITH AMSRD ARL SL BE G DIETRICH E FIORAVANTE C KENNEDY M MAHAFFEY K MANNIX W MERMAGEN A PRICE J SHINDELL R ZIGLER AMSRD ARL SL BM C BARKER G BRADLEY M BURDESHAW P FEDELE R GANGLER R SAUCIER AMSRD ARL SL BS J ANDERSON L BUTLER E DAVISSON D HISLEY B RUTH W WINNER

INTENTIONALLY LEFT BLANK.